

# 12

## Utilities

### 12.1. INTRODUCTION

This chapter considers the major utility systems in a chlor-alkali plant. These include electricity (Section 12.2), steam and condensate (Section 12.3), the various water systems (Section 12.4), air and nitrogen (Section 12.5), and, for convenient grouping, vacuum (Section 12.6). Finding the best basis for a discussion of utilities in a work such as this is difficult. A comprehensive description is impossible in a reasonable amount of space, and in any case it is undesirable where the emphasis is to be on chlor-alkali technology itself. Our approach is to discuss the individual utilities from the standpoint of a chlor-alkali plant operator while avoiding the complexities of such things as steam boilers.

While all utilities are essential to operation, electricity has the greatest cost impact. Still, our discussion of the incoming electrical supply here is brief. Handling and transmission of alternating current within the plant are conventional, and the reader is referred to the standard literature and equipment suppliers' publications. The distinguishing feature of chlor-alkali technology is the presence of large-scale rectification. Discussion of this aspect is more important in a work on chlor-alkali technology, and we have covered it in Chapter 8 on cell room design.

Steam is used in the largest quantities in the evaporation of caustic and, sometimes, brine. A system for the collection and reuse of steam condensate goes hand-in-hand with steam supply. In this chapter, we also consider the use of steam as a source of mechanical power. This is of growing importance as more of the industry adopts cogeneration.

The discussion of water systems includes the most basic treatment of raw water supplies to allow them to serve as plant utility water. More advanced treatment to allow higher-grade uses follows. Evaporator process condensate is included as a special grade of purified water. The most detailed discussions are those dealing with cooling water and chilled water.

Air systems include compressed air as a plant utility and refined versions for more specialized uses. These include instrument air and breathing air. Of particular significance in a chlor-alkali plant is a supply of dry air for use in the chlorine processing section. An alternative to dry air is nitrogen, which also serves as an inert gas in the hydrogen plant and sometimes in chlorine liquefaction and tail-gas handling. For convenience, we include the discussion of nitrogen in the section on air systems.

Important users of vacuum include evaporators and dechlorination systems. Lower levels of vacuum are useful in brine sludge filtration and in clearing lines and equipment for maintenance.

Utility pipelines are a special case in any plant. There is a general discussion of utility piping systems in Section 12.7. This section describes some of the features which one should provide in connections between utility supply and process piping or equipment.

## 12.2. ELECTRICITY

The overriding importance of electricity in chlor-alkali production stems from the huge direct-current (DC) power demand. Some of the special considerations around the conversion of power to DC and its distribution within the cell room have already been covered in Section 8.3. The primary power supply and its transformation and distribution are much the same as in any other process plant. The incoming supply is as alternating current, with 50 and 60 Hz being by far the most common frequencies. Voltages usually are in the thousands—10–30 kV being typical for small plants, but 200 kV and over applying in large plants. For supply of the rectifier transformers, the incoming supply voltage may be suitable, or it may be necessary first to transform it on site to a lower voltage. For other plant supplies, transformation to a lower supply voltage is invariably necessary.

Three-phase power is used almost exclusively as the major source of mechanical power and in plant lighting, but some single-phase circuits also exist. Most plants have a three-phase high-voltage distribution system at 2–5 kV. This is frequently used directly on large drives. For many other applications, voltage is further stepped down to 200–500 V three-phase. Low-voltage single-phase circuits usually follow local practice for domestic supplies, in the 100–250 V range. Instrument wiring, especially in intrinsically safe circuits, is a special category, with voltages below 30.

Incoming voltage and amperage are always measured. A properly connected voltmeter and ammeter can measure single-phase power. The power in a three-phase circuit can be measured by placing a single-phase wattmeter, again properly connected, in each phase and adding the readings. Comparing the result with the line voltage and current allows calculation of the power factor (PF). The same power reading results when using only two wattmeters if each is connected back to the line on the third phase. The PF can be calculated as above or without reference to the voltmeter and ammeter. The latter method uses the asymmetry of the readings of the two wattmeters. If the lower of the two readings is a fraction  $w$  of the higher, the reciprocal of the PF is given by

$$\frac{1}{\text{PF}} = \sqrt{1 + 3[(1 - w)/(1 + w)]^2} \quad (1)$$

Integration of the amperage and power readings over time gives the ampere-hour and watt-hour consumptions of the plant.

### 12.3. STEAM AND CONDENSATE

#### 12.3.1. Steam Systems

Boiler design and operation are highly specialized subjects that require the attention of experts and specially trained operators. Rather than present an inadequate summary of the many factors involved, we refer the reader to suppliers of equipment and services and to the voluminous literature.

Steam is usually made available at two or more different pressures. It is the primary source of thermal energy in a chlor-alkali plant, as it is in most plants in the process industries. It also serves as a source of mechanical energy. Some of the important uses are listed below, with a general indication of the pressure level appropriate to each (L = low, M = medium, H = high).

	Pressure Level(s)
<i>Thermal Application</i>	
Brine processing	
Heating	L,M
Evaporation	L,M
Chlorine processing	
Vaporization	L
Bottoms distillation	L
Condensate stripping	L
Caustic processing	
Heating	L,M
Evaporation	M,H
Purification	M,H
Plantwide	
Tracing	L
Building heat	L
General utility	L,M
Purging (equipment and lines)	L
<i>Mechanical Application</i>	
Ejectors	M,H
Turbine drives	H
Cogeneration	H

The process requirements for steam vary widely, depending on the types of cell being used. Most mercury-cell plants are not major consumers of steam. With diaphragm and membrane cells, most of the process steam goes into the evaporation of cell liquor to concentrated caustic. Diaphragm-cell plants are therefore the largest steam consumers, and membrane-cell plants are the intermediate case. While the range is quite large, depending on supply pressure and the number of evaporator effects used, steam consumption in a diaphragm-cell plant is often about 2.5 tons per ton NaOH. In a membrane-cell plant, it might be 0.5 tons per ton NaOH. Purification of diaphragm-cell

caustic to remove dissolved salt adds even more to the steam load, while the use of a brine evaporator to avoid the need for the purchase of solid salt adds to the load in the mercury- and membrane-cell plants.

Steam pressures applied to first-effect evaporators vary from low levels up to about 2,500 kPa, the high values applying in the first effects of quadruple-effect diaphragm-cell plant evaporators. Even nickel corrodes slowly at these conditions. Section 9.3.2.1 discusses the problem.

Evaporation process design and the characteristics of caustic evaporators are covered in Section 9.3.3. The unit cost of steam is a major factor in deciding the number of effects to be used in evaporation. Costing of steam is often somewhat arbitrary, as when low-pressure exhaust steam is available or when a plant has its own cogeneration system. Reducing the consumption of cogenerated steam (Section 12.3.3) when more electrical energy must be purchased (or less sold) may save very little money.

High-pressure steam may also serve as a driver for turbines. Chlor-alkali plants, which are usually placed in areas of low electrical power cost, are less likely than most other types to justify the use of steam-turbine drives but still may use them as a backup source of power. Furthermore, one of the ways to cope with a major electrical failure is to use steam to operate critical drives until all systems are shut down or electrical power is restored. An example of a critical service is the caustic circulation pump on the emergency vent scrubber. A spare pump is always necessary, and it should have an independent source of power. One way to accomplish this is with a steam-turbine drive. Other services may also be considered critical for personnel safety or process security. The latter is especially true in a membrane-cell plant, where some systems are vital for the protection of the membranes from damage.

Trouble-free generation of steam requires water of high quality. The characteristics of boiler feed water and methods for its production are covered below in Section 12.4.3.3. This water is fed to the boiler(s) on demand. The simplest way to control the addition of water is from a level instrument in the steam drum. This approach has a certain amount of inherent instability. When (cold) water is added to the drum in response to a demand from the level controller, some of the bubbles present in the liquid will collapse. The level will go down, and the controller will call for even more water. In the opposite case, when the level rises and the water flow is reduced, more bubbles will form and the level will increase, causing the controller to call for less water. The process itself is supplying positive feedback.

The control characteristics are improved when a steam flow rate measurement is added. The water feed rate then responds to some combination of steam flow and drum level. Basing the control partly on the steam flow offsets the positive feedback and reduces fluctuations in the supply. Addition of a direct flow controller on the water feed pump output is another elaboration. This would be reset by the outlet steam flow. It provides some feedforward control, which is useful in the presence of severe load swings.

The simplest control scheme is acceptable when fluctuations in the steam rate are minor and when the ratio of water inventory in the boiler to steam production rate is high, making the system less sensitive to fluctuations in demand. The latter is more likely to be true when fire-tube boilers are used. The choice of control system depends on the individual plant characteristics. Chlor-alkali plants tend to have consistent demands for

steam, with few major unexpected changes in rate. Boiler control schemes therefore may be less elaborate than those found in other industries.

### 12.3.2. *Steam Condensate*

Steam condensate is a valuable resource. It has considerable thermal value and some potential uses in the process. However, intensively treated boiler feed water must replace any condensate lost from the system. Accordingly, most plants have systems to capture most of the condensate and return it to the boilers. With steam distributed at several different pressures, it is also possible to allow condensate collected at one pressure to flash down to a lower pressure and in the process form more steam at the lower pressure. Steam is often available at the evaporators well above its condensing pressure, in which case it is worthwhile to install a desuperheater. Condensate is a good source of the coolant.

Most condensate leaves the steam side of the process through steam traps. The chlor-alkali process places no special requirements on the types of trap used, and normal good industry practice should prevail here. Condensate return piping is designed for lower pressure drop than most liquid lines because of the vapor volume that would be generated as the pressure falls. This flashing complicates line sizing, and the designer should use the assistance of condensate system suppliers and their literature.

Plain carbon steel pipe is used in condensate service, but items such as pump parts, valve trim, and exchanger tubes should be copper or a copper alloy. Copper is used for tubing and bronze for pump shafts and glands.

The installation of pumps requires special care to provide enough suction head to avoid cavitation. The net suction head can disappear if a pump generates too much heat in the condensate. It is important to maintain enough flow through the pump at all times to prevent this. Minimum flow can be provided by recycle controlled by an automatic valve or by placing an orifice assembly in a recycle line. As a rule of thumb, a flow of  $1 \text{ m}^3 \text{ hr}^{-1}$  is necessary for each 12 kW of input if the temperature rise is to be kept to  $10^\circ\text{C}$ . The recycle flow must be cooled or go into a heat sink such as a condensate hotwell or boiler feed deaerator. A simple recycle into the pump suction line is inadequate.

When condensate returns to a boiler, it may be contaminated by pipeline corrosion or with process materials. Likely sources of the latter include exchanger leakage and poorly installed process tie-ins. Carbon dioxide and oxygen are the chief causes of corrosion in steam and condensate systems. Section 12.4.3.3 discusses the treatment of boiler feed water to remove these contaminants, as well as hardness.

Hydrazine is one example of a treating agent, but any unreacted material that enters the process is possibly a precursor of nitrogen trichloride. Another is a form of sodium sulfite, a compound that is also used as a reducing agent in brine dechlorination (Section 7.5.9.3A). Since the mechanism of the reaction is different here, proceeding by way of an ion-radical, the sulfite often contains promoters [1]. These would make it less desirable as a brine-treating agent, and plants that use both grades of sulfite should keep them separated.

The presence of amines or any other nitrogen-containing residue in steam condensate restricts its use in process applications. This is especially so when these impurities enter the cells or the chlorine process and eventually form  $\text{NCl}_3$  (Section 9.1.11.2).

### 12.3.3. Cogeneration Systems

The classical approach to energy supply in the process industries has been to purchase electrical energy from a utility supplier and to generate thermal energy on site by combustion of a fossil fuel. This situation arises primarily from the relative ease of transportation of the two forms of energy. Cogeneration, on the other hand, is a process in which both forms are derived from a single primary energy source. The major driving force for the adoption of cogeneration is energy economy. A heat-engine-based electrical generator, for example, rejects heat to the atmosphere if operated as a stand-alone unit. Some of the rejected heat can always be used in the thermal energy supply system without adding to the fuel requirement.

In many cases, generation of one form of energy is the principal goal, and the other form is treated as a by-product. In others, both types of energy are essential products. The smaller need then determines the design capacity of the cogeneration system, and the other form of energy must be supplemented by other means. In all real cases, the power and heat demands vary continually. The cogeneration system most probably will not be able to match all these variations. The ability to sell excess electrical power onto the local grid is an important advantage in such cases, and it has been an important factor in the justification of a number of systems. These and many other factors enter into the decision of whether a cogeneration system is the right choice for any plant [2].

Some of the important factors in selection of a cogeneration system are:

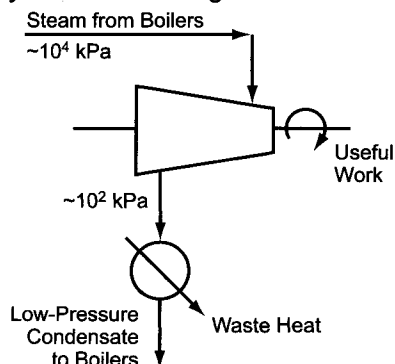
1. capacity range
2. efficiency at design point
3. efficiency at reduced load
4. heat/power ratio at design point
5. ability to vary heat/power ratio
6. ability to change fuels

Internal combustion engines, such as the diesel engine, are the primary source in some smaller units. They require clean-burning fuels with certain characteristics. Closed-cycle power systems with external firing, which are more common in chlor-alkali plant applications, can use almost any fuel.

In a simple open-cycle condensing steam turbine system, steam is raised in a boiler at high pressure ( $\sim 10^4$  kPa). It is expanded through a turbine to generate power, and the low-pressure exhaust is condensed. Depending on the steam pressure, this combination gives a thermal efficiency of about 30%. Most of the loss is waste heat in the exhaust steam that is condensed. The high latent heat of water makes for an inefficient process if the heat is not abstracted in some useful way. Only in special circumstances or with special design can this heat be recovered at low pressure, and in many process plants it is lost in the cooling water system.

A more efficient arrangement from the standpoint of energy recovery is the steam cycle with extraction. Figure 12.1 compares this approach with the open cycle discussed above. Here, some of the steam is withdrawn from the turbine at a pressure suitable for process needs (say 1,000–3,000 kPa) and used as a source of heat. The rest of the steam becomes low-pressure exhaust from the turbine. The performance of this combination depends on the exact conditions chosen. Since much of the steam supplies less of its

## (a) Open-Cycle Condensing Steam Turbine



## (b) Steam Turbine with Extraction

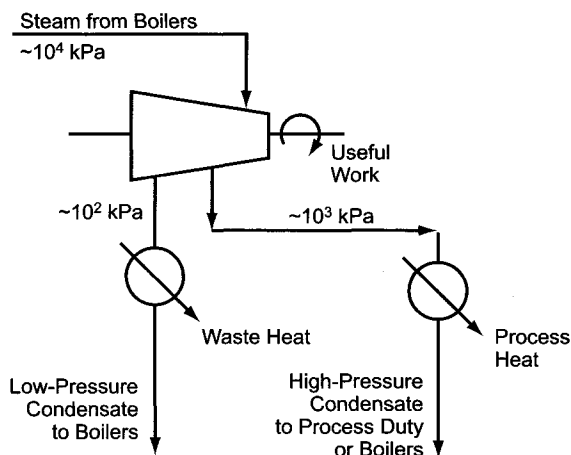


FIGURE 12.1. Comparison of turbine cycles in cogeneration systems.

pressure energy to the turbine, the power efficiency drops, perhaps to as low as 20%. Recovery of some of the thermal energy by extraction of the steam raises the total energy efficiency to 50–55%.

There are other ways to overcome some of the inefficiencies caused by the high latent heat. These include various methods for increasing the superheat of the steam. A small increase in energy content provides a large increase in thermal potential (temperature).

Gas turbines provide an alternative to steam turbines. They must be constructed of materials suitable to the high temperatures associated with combustion gases. Simple gas turbines produce efficiencies comparable to those of simple steam turbines. A combined-cycle unit that also recovers thermal energy benefits from the high temperature of the exhaust gas. Recovery of a major part of this energy, which is possible because there is not a huge latent-heat penalty, can raise the overall efficiency to as high as 80%.

An important criterion in selecting a cogeneration system for a given application is the ratio of heat to power (H/P ratio) required. The demands of a process or an operating

complex can be characterized in this way. Similarly, every turbine system can be defined by its output H/P ratio, and a cogeneration system is ideally designed to match the process demand. This can constrain the operation of a turbine to a certain range of the H/P ratio and limit its efficiency. In other words, extraction of all the available thermal energy from the gas is not practicable. Consider a heat engine with efficiency  $\eta_E$ :

$$\eta_E = \frac{\text{shaft work}}{\text{available heat content of fuel}}$$

In a cogeneration system, the overall efficiency,  $\eta_{OV}$ , is higher by an amount fixed by the H/P ratio, which is designated by  $R$ :

$$\eta_{OV} = \eta_E(1 + R) \quad (2)$$

$R$  cannot increase without a limit. The theoretical maximum corresponding to  $\eta_{OV} = 1$  is

$$R_{\max} = \frac{1}{\eta_E} - 1 = \frac{1 - \eta_E}{\eta_E} \quad (3)$$

The practical maximum corresponding to a combustor efficiency  $\eta_B$  is

$$R'_{\max} = \frac{\eta_B - \eta_E}{\eta_E} \quad (4)$$

where  $\eta_B = \frac{\text{heat to working fluid}}{\text{available heat content of fuel}}$

Figure 12.2 shows the above relationships [3]. The limits are fundamental, and only certain combinations of heat engine efficiency and the H/P ratio are possible.

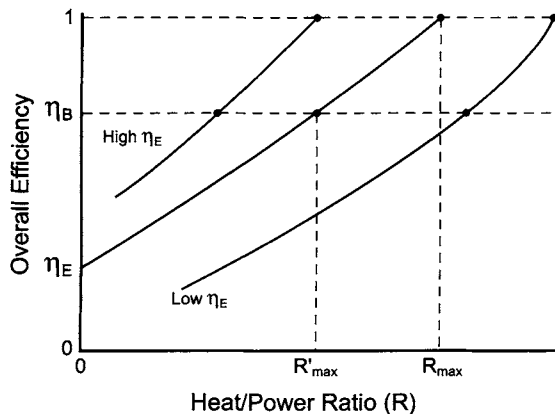


FIGURE 12.2. Operating envelope limitations in cogeneration.



The efficiency of steam turbine cogeneration systems increases relatively slowly with H/P ratio, and so these systems are more likely to be run at relatively low efficiencies. On the process side, the H/P demand of a standalone mercury- or membrane-cell chlorine plant is relatively low, and a turbine-based cogeneration system would run at a correspondingly low efficiency. Diaphragm-cell plants, with the greatest thermal-energy requirements, benefit both from the scale of operation and from a higher H/P ratio. They are the most attractive candidates for cogeneration.

In the chlor-alkali field, many cell installations are part of a larger complex, and the chlor-alkali plant demand is only part of the picture. The H/P demand is higher in an integrated operation such as an EDC, a VCM, or a PVC plant. These are the situations in which cogeneration plants are most likely to be found.

## 12.4. WATER SYSTEMS

Water has a myriad of applications in processing plants. Some of these, denoted by their distribution systems, are

- untreated water from sea, lake, river, or well,
- plant, process, or utility water,
- fire water,
- drinking water,
- sanitary water,
- cooling water,
- chilled water,
- soft or demineralized water,
- process condensate,
- boiler feed water.

Plants located on a body of water often use it as a source of once-through water with a minimal amount of treatment. We do not discuss these systems. The customary approach to fire protection is to provide ring mains around the various process areas, with hydrants and monitors located at intervals and at certain strategic points. There also are distribution lines within buildings and sometimes deluge systems in certain areas. These systems are not very instructive to a student of chlor-alkali technology, and they also are omitted from discussion. Drinking water and sanitary water fall into the same category.

### *12.4.1. Sources of Water and General Plant Use*

Sources include surface waters, wells, seas and estuaries, and recovered condensate. Many plants serve all their needs with municipal water, treated to potable quality, which may be based on surface water or well water. Public water supplies usually carry a fraction of a ppm of chlorine. When used as the principal supply to a plant, these must be dechlorinated before most direct uses in the process.

Before a plant's water treatment system can be designed, a fund of analytical data is necessary. In many localities, these data are available from local authorities or neighboring plants. They should cover a period of time in order to give an idea of variability

as well as average values. Specifically, they should cover the different seasons of the year in order to show variations with the extent of rainfall, runoff of melted snow, or mixing of underground aquifers. The following data and analyses should be available, in addition to analyses for individual ions [4]:

- total dissolved solids (TDS)
- total suspended solids (TSS)
- total organic carbon (TOC)
- conductivity
- turbidity
- silt-density index (SDI)
- pH
- silica
- carbon dioxide
- chlorine (in the case of municipally treated water)
- temperature range

Local regulations governing the plant effluent will also affect the choice of water treatment processes.

The quality of natural water is extremely variable. Surface waters are generally turbid. Well waters, while clear, may have high hardness. There are also wide variations in the quality demanded by various uses. Therefore, the sort of treatment to be applied, depends both on the quality of the raw water and on the intended use.

Frenkel [5] classifies raw water supplies into several types with different characteristics (Table 12.1). Other authors propose similar classifications and often add hardness to the list of characteristics. Arden and Forrest [6] take a modular approach to treatment. Silted river water, for example, considered suitable only for irrigation, is improved by sedimentation to a quality comparable to that of most other surface waters. The clarified water then becomes suitable for crude industrial applications. Coagulation and filtration then virtually eliminate suspended solids and make the water suitable for general purposes. These include plant utility use without necessarily qualifying the water for process application. Beyond this point, the intended application determines the extent of treatment required.

The first column in Table 12.1 indicates that the turbidity of river and lake or pond water is highly variable. Rivers are especially turbid during rainy seasons or at the time

TABLE 12.1. Selected Characteristics of Natural Waters

Source	Turbidity	TSS	Color	TOC	TDS	SDI	Stability
River	H**	H*	M	M-H	L	VH	VL
Lake or large pond	L*	L*	H*	H*	L	H	VL
Well	L	L	L	M-H	L	H	M-H
Brackish	L	L	L	L-M	M-H	H	H
Sea	L-M	L	L	L-M	H**	H	H

Notes: L, low; M, moderate; H, high; V, very; TSS, total suspended solids; TOC, total organic carbon; TDS, total dissolved solids; SDI, silt-density index.

\*Seasonal variation, \*\*Highly variable.

Source: Frenkel [5].

of the spring thaw. Lakes become more turbid and can develop more color in warm weather. The other sources are more stable throughout the year. All are subject to some change. Open seawater can have moderate seasonal changes and be disturbed in stormy weather. The quality and rate of inflow of fresh water influence the characteristics of the water taken from bays and estuaries. The ability to cope with these variations is an important aspect of treatment system design.

The treatment of water is quite similar to the treatment of brine, discussed in Section 7.5, but there are certain differences in each step. The first objective is the removal of suspended solids, which would interfere in most of the subsequent steps. Preliminary clarification of highly turbid water occurs in a standard circular clarifier or in an elongated rectangular basin. This is sometimes combined with cold lime softening or with the addition of coagulants or flocculants. Coagulation differs from the process of flocculation described in Section 7.5.2.2D. It is aimed at colloids rather than at formation and growth of precipitates from dissolved species [7]. Colloidal particles, submicron in size, stay in suspension because of Brownian motion. Coagulants destabilize colloidal suspensions by overcoming the electrical repulsion between particles. The colloids, of which clay and silt are typical examples, tend to carry negative charges. The Hardy–Schulze rule states that the important ion in a coagulant is the one whose charge is opposite to that on the particles and that the power of the coagulant increases dramatically as the magnitude of the valence of the key ion increases. Multivalent cations will then be the best coagulants, and they are hundreds of times more effective than monovalent ions. Iron and aluminum salts are most frequently used, at concentrations of 10–30 ppm in the water. Ferric chloride (Section 9.1.9.4) is a widely used coagulant. The chlor-alkali producer, especially the operator of membrane cells, will find it easier to remove iron compounds in subsequent brine processing.

In removing suspended solids, clarifiers improve some of the other measures of water quality. These include color and organic content. A typical clarifier product will have less than 10 ppm suspended solids.

Filtration normally follows sedimentation. Industrial practice again resembles brine treatment (Section 7.5.4). Bed filters may contain a single medium, usually operating in a downflow mode, or several layered media. The latter usually operate in an upflow mode, with the water sequentially meeting gravel (for support), garnet, sand, and anthracite. Membrane filters are finding increased use in water treatment [5]. Microfilters can remove particles down to 0.1  $\mu\text{m}$  and do not require pretreatment of the water. Ultrafilters remove particles down to 0.01  $\mu\text{m}$  but frequently require pretreatment of the water. These filters can remove colloids and normal organic matter (NOM).

Filtration can be used without sedimentation, but filters have limited solids-handling capacity. Frenkel gives these rough guidelines for the choice of the primary solids-removal equipment:

TSS	Equipment
<10 ppm	Membrane filter
10–100 ppm	Media filter
>100 ppm	Clarifier

The low-solids waters become suitable for drinking and sanitary purposes after chlorination. The addition of corrosion inhibitors, and antiscalants when hardness is present, makes them usable in cooling water circuits. In-process application may require further treatment, and demineralization by ion exchange is perhaps the most common technique in chlor-alkali plant practice. There is a large literature on the technique of ion exchange, and Section 7.5.5 discusses its application to brine softening. The complexity of the system depends on the nature and concentrations of the impurities in the water. The basic ion-exchange system includes separate columns of cation- and anion-exchange resins. The exact choice of resin depends on the process duty and the nature of the water. Enhanced systems may include decarbonization by volatilization of  $\text{CO}_2$  and a final column of mixed cationic and anionic resins. Strong-base anion resins can remove silica (Section 12.4.3.1), a property that may be useful especially to membrane-cell operators. Continuous operation requires parallel units, and acid and caustic regeneration of spent columns is necessary.

Some plants also produce their own potable water by treating a well or groundwater supply. This is not a common situation, and it is a specialized subject that will not be covered here. Most plants receive potable water from a local supplier or municipality. This water is used for drinking and sanitary use and usually in safety shower/eye wash systems. In some cases, the municipal potable water supply also serves as a general plant utility. Drinking water systems must always be kept separate from plant service systems. The method of separation is often prescribed by local regulations. Backflow preventers are a standard, but dedicated tanks that provide physical breaks are more positive and in many locations are required. These are discussed in Section 12.7.2.

### 12.4.2. *Water as Heat Sink*

**12.4.2.1. Cooling Water.** When a source of water of the proper quality and a reliably low temperature is available, it may be used on a once-through basis to remove process heat. This may be true of certain municipal water supplies, but they are usually too scarce or expensive for such use. It is more common to find seawater or river water in such an application.

Most chlor-alkali plants use water in a closed circuit to remove waste heat from the process. The heat is then rejected into the atmosphere by cooling the water itself by direct or indirect contact with air. Dry systems using indirect contact are useful in some situations, but the typical chlor-alkali plant uses direct contact. The nearly universal choice for this operation is the cooling tower, where heat transfer and mass transfer occur simultaneously by direct contact between phases. Sections 9.1.3.2 and 3 discuss these transfer processes in connection with the cooling of chlorine gas. The effectiveness of a cooling tower depends on the distribution of water and the means used to promote contact between the water and the air. The internal arrangements of a typical unit are discussed below.

The water cools by supplying its own latent heat of vaporization. It is therefore possible to cool the water below the dry-bulb temperature of the air supplied to the tower. The real measure of the cooling potential of the air is its wet-bulb temperature, and each tower is designed to operate at a certain inlet wet-bulb temperature.

The function of a cooling tower is, quite simply, to remove heat. However, a tower cannot be rated solely in terms of heat transfer. It will remove as much heat as the process generates even when loaded beyond design conditions. If the amount of heat to be removed increases, the tower evaporates more water to match the new rate of heat input. What changes is the temperature of the circulating water. Increases in that temperature will eventually affect process performance.

Definition of the duty of a cooling tower therefore becomes rather complex. Manufacturers' and technical literature covers the subject thoroughly. Standard thermal tests have been developed that take into account the complexities. These include ASME PTC-23 and the Cooling Technology Institute's ATC-105.

The most important specifications are the water flow rate and the range. The latter refers to the change in the temperature of the water as it passes through the tower. A specification derived from this is the "approach," which is defined as the difference between the wet-bulb temperature of the incoming air and the temperature of the outgoing water. The approach is the most influential variable determining the size of the cooling tower. Figure 12.3, a combination from several sources, shows its powerful effect.

The wet-bulb temperature used to specify the duty of a cooling tower is that which is exceeded only a certain percentage of the time during the year. In compilations of meteorological data, it is customary to list wet-bulb temperatures in this way. Frequently, these lists show data at the 1, 2.5, and 5% levels. It is important to note that, for a given location, the temperature differences between levels are not great [8]. Data for nine plants in Texas show an average difference of less than  $1^{\circ}\text{C}$  between the 1% and 5% temperatures. A commonly used basis is 2.5%. This does not mean that an exchanger, or the plant as a whole, can meet its capacity only 97.5% of the time. By superimposing the daily temperature cycle on the yearly, we would see that the design wet-bulb temperature is usually exceeded for only a few hours at a time. The thermal inertia of the cooling water system helps to dampen the effects of these temperature peaks. Furthermore, unless an exchanger operates with a narrow temperature pinch, an increase above the design water temperature will produce only a small decrease in its capacity. Usually, intentional overdesign and allowances for fouling are much greater than this decrease. Taking one commercial design at random, the authors found that an increase of  $1^{\circ}\text{C}$  in cooling water

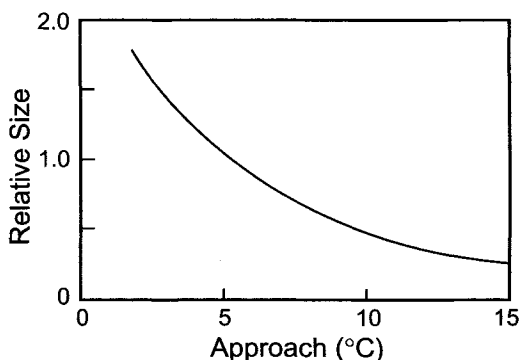


FIGURE 12.3. Influence of temperature approach on size of cooling tower.

temperature would reduce the capacity of a chlorine cooler by less than 5%. The safety factor in the amount of exchange area above that calculated to be required was 7%. The fouling factor applied to the water side of the cooler increased the amount of surface provided by 25%. Unless this exchanger is severely fouled, it should meet its design capacity even when the 97.5% wet-bulb temperature is exceeded.

When cooling water is used to cool dry chlorine, any leakage from one side of an exchanger to the other will produce a highly corrosive mixture. If water leaks into the chlorine, the effects will be more rapid and more severe. It would be better to have chlorine leaking into the water and out of the process. Therefore, the water used in an exchanger should be kept by means of a regulator at a lower pressure than the chlorine. This may require the water leaving the exchanger to be collected and pumped into the return header. A chlorine leak normally is easily detected by monitoring the conductivity of the water. Some plants located near the sea use once-through seawater as a coolant. In this case, conductivity is not sensitive to small amounts of chlorine. Oxidation–reduction potential can be used instead. The use of chlorine monitors in cooling tower fan stacks is also becoming more common. This provides a check on the other instruments and an aid in environmental reporting.

A problem specific to cooling towers is the presence of *L. pneumophila* bacteria. The disease they carry has a high profile, and they are difficult to control with conventional biocide programs [9]. Transmission is primarily by inhalation of aerosols [10], and this is one reason to install drift eliminators (see below) and to arrange the tower so that the drift is primarily into unpopulated areas of the plant.

**12.4.2.1A. Construction of Cooling Towers.** Cooling towers include atmospheric spray towers, natural-draft towers, and mechanical-draft towers. The first type uses the momentum of water to draw air in cocurrent flow down through the tower. It seldom appears in chlor-alkali plants. Natural-draft towers by their nature are quite large and likewise are not common in the chlor-alkali industry. These are the large hyperbolic units associated with the power industry that are usually the first objects seen when approaching a generating plant.

Mechanical-draft cooling towers are the type most often found in the process industries. These provide their own air flow, and wind direction and velocity therefore do not greatly affect their thermal performance. They can be classified in several different ways:

1. according to the relative directions of entering air and water flows (counterflow or crossflow);
2. according to the method of producing draft or the location of the air movers (forced draft or induced draft);
3. according to the type of fill used to spread the water and increase its area of contact with the air (film or splash bar).

Counterflow, as would be expected, allows more efficient transfer of heat and mass. With the application of a modern high-efficiency fill, the counterflow tower has become the most effective and most compact type of unit [11]. It is less open in its construction than the crossflow type. This reduces the penetration of sunlight and the rate of growth of

algae. The crossflow tower, as will be seen below, has its own advantages and has been the standard in most chlor-alkali plants. It is more tolerant of suspended solids in the water and is favored by plant maintenance departments because of the relatively easy access to its internals, which include distributors, fill, structure, and drift eliminators.

Induced draft generally requires less energy to move a given amount of air and produces higher velocities through the fans ( $400\text{--}800\text{ m min}^{-1}$ ). The latter is important in helping to reduce the amount of recirculation of warm, wet air into the tower. With induced draft, it is also easier to achieve good distribution of air over a large cross-section.

The typical fan is a multiple-bladed propeller. Tip speeds usually are held to less than  $70\text{ m s}^{-1}$ , and vibration switches protect the fans from mechanical damage. Fan guards are essential for personnel protection. The typical induced-flow tower has a cage of heavy galvanized wire surrounding each fan. Variable-speed fans can be slowed down to regulate the air flow for low-capacity operation. With the wide range of duties encountered over the course of a year, common practice is to supply multiple units and to shut them down individually when the load is low.

Two problems associated with the air leaving a tower are drift and recirculation. “Drift” is entrained water. Massive amounts of drift would waste water. Normal drift, usually less than 2% of the circulation rate, does not affect the fresh water consumption, because greater quantities must be removed, in any case, in order to control the dissolved solids concentration. The problem with drift is that even small amounts can cause problems of fog formation, deposit of dissolved solids, and icing of surfaces. The internals of a cooling tower are designed to suppress drift. Figure 12.4 shows the presence of drift eliminators, which are baffles that allow entrained water to separate from the air. They do this by forcing sudden changes in the direction of the air flow. This allows the water impinging on the surfaces to separate from the air. It also helps to redistribute the air by creating a pressure drop. The eliminators may resemble simple baffles, being formed from wooden or plastic slats mounted in frames. Thin-walled honeycomb structures are another form that is frequently used. “Recirculation” is the reentry of discharged air into a tower. This raises the dry-bulb temperature and, more importantly, the wet-bulb

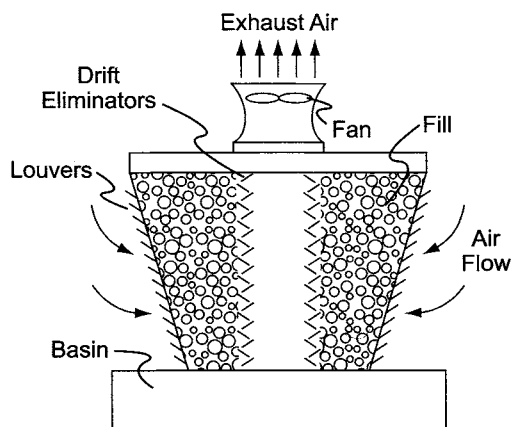


FIGURE 12.4. Induced-draft cooling tower.

temperature of the incoming air and limits the ability of the tower to cool the water. Keeping the discharge velocity of the air high, isolating the towers from other structures that can produce downdrafts, and orienting the towers to counteract the effects of prevailing winds can reduce the amount of recirculation. Occasionally, the steam plume from a tower becomes a third problem.

We take Fig. 12.4 as representative of a chlor-alkali plant cooling tower. Air enters through the sides of the tower, which are louvered. It moves under the influence of the fan mounted on top of the tower. Returning warm water enters the top through a distribution system and falls through the tower. Gravity distribution is acceptable in crossflow towers and has the advantage of requiring no pressure energy at the point of delivery. A head box is mounted above each cell of the tower, and levels can be adjusted independently. The water at the top of the tower is the most corrosive. It is warm and aerated and has a high concentration of dissolved solids. Resistant materials are required in this zone. Redwood is the favored wood, and plastics and galvanized steel are also used.

The tower sits above a basin, which serves as its foundation and also collects the cool water. The sump should be sized to allow refuse and suspended solids to settle, and it should be designed to allow on-line cleaning. Provisions might include a bottom sloped to the center, where a central pipe can carry off the settled solids, or a slope to one side, which when extended beyond the end of the tower, allows easy access for a suction hose. Concrete is the standard material of construction for cooling tower basins.

A set of pumps in a pit recirculates the cooled water. Submerged vertical pumps are standard in this service. When using multiple pumps with large capacities, it is necessary to space them properly and to design the pit to allow unimpeded access of the water flow to the suction of the pumps. The requirements of the pump vendors will fix this aspect of design. Any reverse flow through idle pumps recycles to the basin and reduces the efficiency of the process. Check valves and anti-reverse mechanisms help to prevent this.

The basin and the pit may be connected by a series of flumes. Screens constructed of fiber-reinforced plastic (FRP) or steel and mounted vertically in the flumes remove some of the suspended solids from the water. The cross-section of a flume may be small enough to allow a screen to be removed by one person. If not, some mechanical device becomes necessary. It is good practice to mount more than one screen in each channel, so that the water is still filtered when one of the screens is removed for cleaning. Flow into the flumes should be over a weir in order to retain the settled solids in the basin.

Settling and screening are a crude approach to solids separation, but they are effective in removal of trash and large particles. It may be necessary to remove finer solids as well. This can involve whole-stream filtration or filtering a sidestream and either returning it to the basin or pit or joining it with the main cooling water supply.

Clean makeup water can be introduced directly to the pump pit. Dirty water is better fed to the sump, where there is some opportunity for settling of solids. Treatment chemicals can be introduced anywhere in the system. Addition into a flume helps to mix the treating agent into the main water flow.

Wood is the standard material of construction for cooling towers. The Cooling Tower Institute publishes standards for construction from various woods and for treatment of the wood with preservatives. Almost paradoxically, fire protection is very important in cooling tower design, because the common practice of shutting down units or modular cells during times of low demand can allow wooden units to dry out. There should be a



hydrant nearby and sprinklers over and around the tower. The fan(s) should be interlocked to shut down whenever the sprinklers operate, and the startup procedure should call for starting water flow before starting the fan(s).

The trend now is away from wooden construction. With advances in fabrication techniques for plastics, preassembled plastic towers are now being used in larger size [12]. These are available in modules with ratings up to  $10 \text{ GJ hr}^{-1}$  cooling load. While they cost about 20% more than most wooden towers, they are more easily installed. Fireproofing is not necessary, and the tower blowdown contains no preservatives.

Drying of the wood should be prevented by periodically wetting the idle zone. A shutdown switch should also be available at a distance of at least 5 m from the tower. The vicinity of a cooling tower should be a no-smoking zone. All hot work and temporary wiring should be carefully supervised and checked.

**12.4.2.1B. Cooling-Tower Fill.** The type of medium used to subdivide the water determines the amount of interfacial area available for heat and mass transfer. This material, referred to as the “fill,” usually is of one of two types, film or splash bar [11].

Film fill consists of corrugated or rippled sheets that subdivide the water and provide interfacial area. These sheets are assembled into packs that are installed vertically and stacked at offset angles. This is the more efficient of the two types of fill, but it is more difficult to install properly. Solids are more likely to deposit in the fill, and maldistribution of water is more likely.

Splash bars are less sophisticated and less effective. Staggered rows of horizontal bars form small droplets by impingement of the water. The water falling through a tower cascades from one row of splash bars to the next and so is continually subdivided. The support grids usually are of FRP. The bars themselves may be PVC, polypropylene, or wood. The plastic materials are less combustible than wood. While the effectiveness of this arrangement is less than that of the film fill, again, construction is simpler and maintenance access is much easier.

The trend in the industry is now in the direction of more efficient packing.

**12.4.2.1C. Piping and Instrumentation.** Cooling water piping is usually carbon steel. This fact makes it essential for the plant operator to keep up with the water treatment program. Untreated cooling water is the most corrosive form. Most plants at least add inhibitors. These vary in composition, and it is difficult to generalize other than to say that chromates, once a standard, are now seldom used, because of their toxicity.

Scaling and corrosion both are problems in cooling water piping. Calcium carbonate is the most common scalant. When sulfuric acid is used in the treatment program, this is converted to the sulfate. Calcium sulfate has less tendency to precipitate and scale the piping, but it is harder to remove when present.

Most exchangers have block valves in both cooling water connecting lines in order to allow isolation for maintenance. Improper closing of these valves with the exchanger under load will allow trapped water to heat and expand. This can damage the equipment or the piping, and some means of prevention is necessary. Most common is the addition of a thermal/pressure relief valve between the exchanger and one of the valves. This device simply opens at high pressure and allows a small amount of water to escape,

relieving the pressure. These relief valves are simple units, and in the absence of steam generation in the exchanger are quite small, usually 15–20 mm in diameter.

Each exchanger should have water-temperature instrumentation. The minimum case is a simple thermowell in the water outlet line. The most elaborate is permanently installed temperature indicators on both inlet and outlet. These instruments serve first as a means of checking the temperature profile against design and as crude indicators of the amount of water flowing. They can also be used for troubleshooting if enough information is available to construct a heat balance across the exchanger.

On the water side, particular problems are the corrosion potential of the water and the accumulation of dissolved solids.

12.4.2.1D. Concentration Effects and Blowdown. Comparison of the normal increase in cooling water temperature in the process with the latent heat of water shows that about 1–2% of the circulating water will evaporate on each pass through the tower. This must be replaced by makeup water, which brings more dissolved solids into the system. The process of treatment of the circulating water also adds dissolved solids, and one must consider the total concentration in the mixed feed water and treating solutions. Some water must then be withdrawn from the system in order to limit the dissolved solids concentration. This purge, or “blowdown,” acts along with the drift to remove both water and solids. Evaporation removes only water. The concentration factor for total dissolved solids in the recirculating water above that in the combined system makeup is

$$C = \frac{(E + L + B)}{(L + B)} \quad (5)$$

where

$C$  = concentration factor

$E$  = rate of evaporation

$L$  = rate of mechanical loss of water

$B$  = rate of blowdown

Mechanical losses include leaks, in-process applications of cooling water, and drift. To maintain a certain concentration factor, the required blowdown rate is

$$B = \frac{E}{(C - 1)} - L \quad (6)$$

The form of Eq. (6) shows that in order to maintain the concentration, the sum of  $B$  and  $L$  must be held constant. Efforts to reduce mechanical losses ( $L$ ), while useful in themselves, do not always reduce the usage of water.

Many different corrosive agents can accumulate in a closed cooling water system if the concentration factor is too high. The use of inhibitors, noted above, is a standard technique. Upgrading the materials of construction also can prolong the life of equipment. Parkinson [13], for example, describes the use of a 75- $\mu\text{m}$  coating of electroless nickel on cooling water pumps.

Blowdown creates a waste disposal problem and cooling towers, even aside from drift, can pollute the air. These disadvantages, combined with the growing shortage of water in parts of the world, have contributed to the beginning of a trend to dry cooling.

12.4.2.1E. Process Control. There are many different approaches to control of the cooling water treatment and blowdown process. Figure 12.5 is an example. The dissolved solids concentration is indicated by the conductivity of the water. This property is used to control the rate of blowdown. The blowdown, the evaporated water, and any system losses are replaced by makeup water, added under sump level control or through a float-operated valve. In a different approach, the rate of blowdown is made proportional to the rate of makeup water addition.

Most treating agents are fed in proportion to the makeup water flow. Analysis of the circulating water then may call for occasional changes in the ratios. The “chemical feed” of Fig. 12.5 is an example. There may be more than one such system, feeding inhibitor and other additives. The controller may adjust the speed or the stroke of the chemical feed pump. Alternatively, it may call for periodic feed of a certain volume of

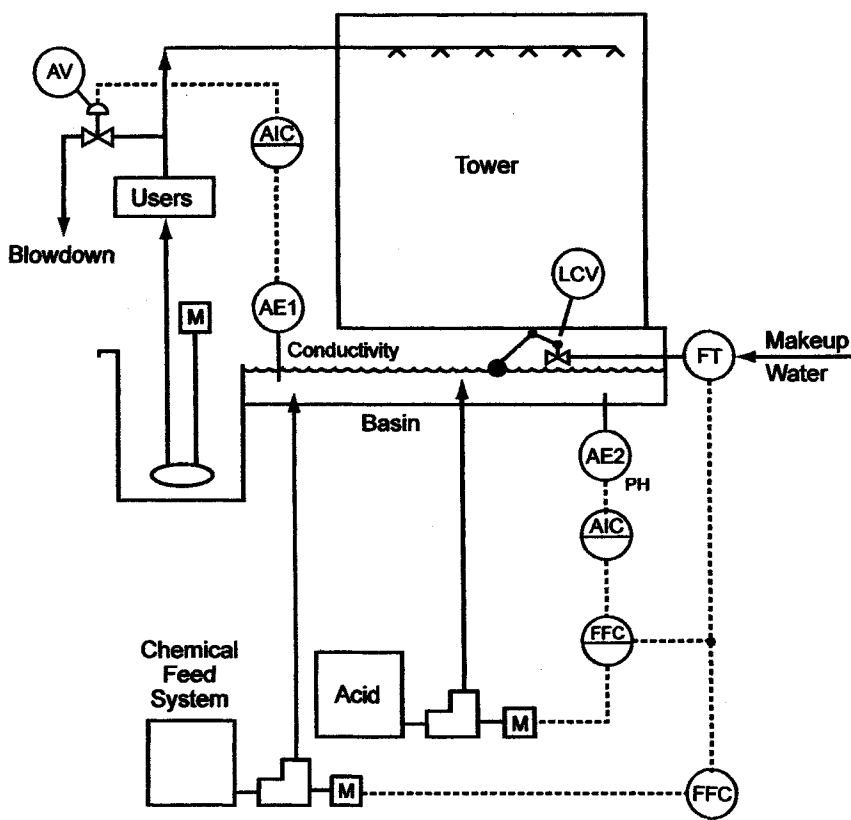


FIGURE 12.5. Cooling-tower water treatment process.

solution, with the length of the period inversely proportional to the makeup water rate. Minor ingredients may be added infrequently and manually. One technique is to charge them to a bypass tank connected to both cooling water headers and then to allow some of the supply water to flow through the tank and into the return header. Concentration control can be open- or closed-loop in nature. The control of pH is a special case that demands a proper dedicated control system. Sometimes there are two acid feed streams, with the larger proportional to the makeup water and the other responding directly to measured pH.

The treatment of cooling water is a subject for specialists. Requirements are affected by the quality of the water supply; the extent of contamination by corrosion products, process leakage, and the use of the water in direct-contact applications; and the nature and quantity of solids and gases scrubbed from the air in the cooling tower. There are extreme variations in some of these factors, and each plant will need its own treatment system and program.

*12.4.2.2. Chilled Water.* Chilled water is special in the sense that it may be provided not as a central utility serving a complex but rather from a unit dedicated and belonging to the chlor-alkali plant. We shall therefore consider it in more detail than we do some of the other utilities.

Its major users are the secondary chlorine cooler (or chiller) and the product caustic coolers in a diaphragm-cell plant. The latter are used to drop the final product temperature below normal cooling water temperatures in order to reduce the dissolved salt content. Other users sometimes include secondary hydrogen coolers, the sulfuric acid coolers at the drying towers, the water spray at the entrance to the wet gas demister, and acid coolers on liquid-ring pumps.

Water can be chilled at a central location by a dedicated refrigeration unit. Alternatively, refrigerant brine distributed as a general utility can be used to chill plant cooling water as and where necessary. After use, this water is sent to the cooling water return system. This becomes a standard application for a utility, and we do not consider it further.

Water chilling units in most chlor-alkali plants are not large and are usually purchased as packages. The thermal duty of a water chiller should be kept low as a matter of economy. The goal should be to approach the desired process temperatures as closely as possible through the use of cooling water. The practical limitation on this approach can be the rapidly increasing size of the primary coolers as their mean temperature differentials become smaller.

Note once more that seasonal cooling water temperatures may be lower than the minimum temperatures allowed in the chlorine and 50% NaOH processes. The plant then should operate with tempered cooling water and not with chilled water.

Chilled water supply involves a closed circuit. The water flows through a supply header, the users, and a return header to a storage/pump tank. Demineralized water is a typical source. It is added occasionally to replace water lost from the system or deliberately purged to remove contaminants such as process fluids and corrosion products. Storage tank construction is simple. The pressure is essentially atmospheric and the temperature is low. Since water is more corrosive when aerated, the tank may be blanketed, and plain carbon steel construction should be avoided. Lined steel and FRP are acceptable materials of construction.

For a given heat load, the flow of chilled water is greater than that of cooling water. This is because the temperature rise in service is restricted in order to keep the chilled water supply temperature relatively high, thereby reducing the power consumed in refrigeration.

Diaphragm-cell plants have the highest demand for chilled water. The NaOH-chilling load will be about three times as great as the chlorine-chilling load. This ratio is a function primarily of cooling water temperature. As that temperature increases, the intermediate process temperatures rise, and so the residual loads on both chillers increase. The available cooling water temperature fixes the demand. As the chlorine or caustic soda emerging from the cooling water section of the process becomes colder, the chilled water duty becomes less. As a result, water chillers seldom operate at design duty. When the annual swing in cooling water temperature is large, they may operate much of the time at a small fraction of design duty. Wide capability for turndown is very important.

Most water chillers in the chemical industry operate close to the freezing point of water in order to provide the maximum thermal potential. In our most important applications, however, there is a minimum desirable water temperature, set by the formation of chlorine hydrate, the loss of passivation of titanium surfaces in chlorine service, or the freezing of caustic soda. The water chiller can be operated at a higher outlet temperature than usual, or if colder temperatures are required somewhere, the water can be tempered for the major uses.

The duty of a chilled water system depends primarily on the cooling water temperature. Since nearly all cells operate close to atmospheric pressure and since chlorine outlet temperatures usually are 13–15°C, the end point of the chlorine chilling process is nearly constant. The starting point depends on the temperature of the gas leaving the cooler, which in turn is a function of the available cooling water temperature. Similar arguments apply to the cooling of diaphragm-cell NaOH.

Figure 12.6 shows the effect of gas temperature from the cooler on the chiller heat load. The basis is one ton of gas that is 100% chlorine (dry basis) at atmospheric pressure.

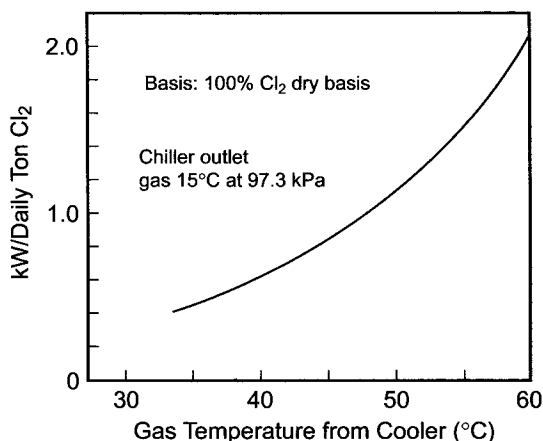


FIGURE 12.6. Thermal duty of a chlorine chiller.

The effect of gas impurities is to increase the volume of gas without changing the partial pressure of water. The latent heat component of the heat duty is therefore inversely proportional to the dry-basis mole fraction of chlorine. The same proportionality would hold for the sensible heat component if the impurities had the same average molar heat capacity as chlorine. While this is not precisely the case, the differences are small in comparison with the latent heat duty, and the assumption of constant  $c_p$  causes very little error. Figure 12.6 can, therefore, be used as a first approximation to the chiller load by dividing the indicated number by the mole fraction of chlorine.

Because cooling water is the ultimate heat sink in the water-chilling process, higher cooling water temperatures also increase the cost of refrigeration. In a mechanical system, for example, the refrigeration condenser temperature will be higher. This increases the compression ratio in the system and, therefore, the energy consumed by the compressor. Chillers use standard compressors, usually of the centrifugal or screw type. The condenser and evaporator are typical of industrial refrigeration service in their use of finned tubes formed from a copper alloy. In the operating range of 10–15°C, they consume about 70–80 kW hr GJ<sup>-1</sup>.

*Example.* In our reference plant, the cooling water is available at 30°C and cools the chlorine gas to 40°C. We then wish to cool the gas to 15°C with chilled water. The gas leaving the cells contains, on a dry basis, 97% chlorine. We allow another 1% for entry of air. Figure 12.6 then indicates that our chilled water duty on a 100%-chlorine basis is 0.604 kW/daily ton. We therefore require  $0.604/0.96 = 0.63$  kW/daily ton = 446 kW.

**12.4.2.2A. Mechanical Refrigeration.** Mechanical refrigeration is the most popular approach in chlor-alkali plants. The other techniques discussed below have advantages when electrical power is expensive. If that is the case, perhaps the chlor-alkali producer is in the wrong business.

Section 9.1.7.1 on chlorine liquefaction briefly describes the typical mechanical refrigeration cycle. Several different types of compressor appear in water chillers. They include reciprocating, screw, and centrifugal machines. The best choice depends very much on the suitability of a manufacturer's package details. The choice of refrigerant is not constrained by reactivity, as in the case of chlorine compression.

Since the demand for chilled water is highly seasonal, the refrigeration load is usually well below the design maximum. There is an excellent case here for multiple-stage unloading of compressors and for the installation of two partial-load machines.

**12.4.2.2B. Steam-Jet Refrigeration.** Under sufficient vacuum, water will boil; the latent heat of the steam formed comes from the remaining liquid, which is cooled in the process. The pressure level determines the temperature of the cooled water. One stage of eduction will accomplish the temperature reduction, but steam economy improves when several stages are used. Both the motive steam and the water vapor generated by evaporation flow to a condenser system. Most frequently, this will also be in more than one stage. Much of the load can be removed in a barometric condenser. The overall energy economy improves if a compressor and higher-pressure surface condenser follow in a later stage.

The amount of steam required to produce a given quantity of refrigeration is a function of the pressure of the supply and the condensing temperature. With steam at 7 bars and an ambient wet-bulb temperature of 25°C, about 600 kg of steam produces a gigajoule of refrigeration. As a rule of thumb, a small (say, 5 GJ) unit produces 1.6 GJ of refrigeration from 1 kW, 1 ton of steam, and 100 m<sup>3</sup> hr<sup>-1</sup> of cooling water (10–12° rise). Note that makeup water is required continuously to replace that evaporated by the steam jets.

**12.4.2.2C. Absorption Refrigeration.** Water is the refrigerant in the absorption process. To allow it to evaporate and condense at the right temperatures, the whole process is under vacuum. There is no compressor between the evaporator and the condenser. Rather, the water vapor from the evaporator is picked up by absorption in a salt solution. Lithium bromide is the salt most frequently used.

The cycle includes

1. evaporation of water from LiBr solution by low-pressure steam or hot water;
2. condensation of water vapor from (1) at about 10 kPa by plant cooling water;
3. evaporation of water from (2) at about 1 kPa by exchange with the process load (circulating chilled water);
4. absorption of vapor from (3) by dilute LiBr solution, with the heat of absorption removed by plant cooling water;
5. pumping of solution from (4) to the concentrator to continue the cycle;
6. exchange of heat between concentrated LiBr from (1) and concentrator feed (5);
7. recycle of absorber solution, joined by concentrated LiBr after cooling in (6).

Containment of LiBr and maintenance of vacuum are essential. A small amount of air in the refrigeration loop can make the process inoperative. All components of the refrigeration loop may be mounted in one shell in order to reduce the potential for inleakage.

### *12.4.3. Purified Water*

Water, after the preliminary treatment methods of Section 12.4.1, can be called “purified.” Here, we use the term to refer to the higher levels of purification in Table 12.1 or to those processes which remove dissolved contaminants. In the chlor-alkali process, the major uses of purified water are dilution of catholyte, processing of membrane-cell caustic liquor, preparation of ion-exchange system regenerants, manufacture of hydrochloric acid, acidification of brine, and, sometimes, dissolving of salt. It also serves as utility and seal water in the membrane preparation area and in certain parts of the process.

**12.4.3.1. Softened and Demineralized Water.** Ionic contaminants are removed from water by softening or demineralization. The softening process removes the hardness elements (and other multivalent cations) that are of major concern to the chlor-alkali producer. Chemical softening was the first process developed, but modern plants use a cation-resin process. Exposing water to a resin containing labile sodium ions allows the removal of divalent cations and their replacement with sodium. The chemistry is that discussed in Section 7.5.5.1. When the resin is nearly saturated with hardness ions,

contact with a concentrated solution of NaCl restores it to the sodium form and produces a waste stream. Note that softening does not reduce the total ionic loading in the water. It simply replaces some of the impurities (hardness ions) with less objectionable impurities (sodium ions). The anionic population does not change.

Demineralization is another resin-based process. It removes essentially all the ionic contamination from water. The cation resin here is in a different form and contributes hydrogen rather than sodium ions. A second resin is necessary for the removal of anions. The labile ion on this resin is  $\text{OH}^-$ . When this replaces the other anions in the water, it combines with the  $\text{H}^+$  released by the cation-exchange resin to form water.

Silica and carbonate are special considerations in the design of demineralization systems. The carbonate content can be removed by stripping  $\text{CO}_2$  from acidic water, rather than by using solely the ion-exchange resin for this duty. Silica is the anhydride of the weak acid  $\text{H}_2\text{SiO}_3$  (pKs at room temperature 9.7 and 12.0). This fully ionizes only when in contact with a strong base. Removal of silica by ion exchange, therefore, requires the use of a strong-base resin. Such a resin is more expensive than the more conventional weak-base type and usually has a lower total exchange capacity. Depending on the capacity and on the desired degree of dissolved solids removal, the demineralizers can be designed in several different ways:

1. with single beds each of weak-base cation- and anion-exchange resins
2. with single beds of strong-base cation- and anion-exchange resins
3. combination (1) followed by a bed of mixed cation- and anion-exchange resins, the cation resin being of the strong-base type (this arrangement may also include a carbonate decomposer and stripper)

Regeneration of any ion-exchange bed produces a waste product. Section 16.5.2.4 covers the disposal of these streams.

**12.4.3.2. Evaporator Condensate.** Diaphragm- and membrane-cell plants produce useful condensate in their caustic evaporators. As the material balance of Fig. 6.9 shows, the membrane-cell evaporators produce more than enough condensate to serve the demand for dilution water in the cell room. Diaphragm-cell evaporators, with their much higher evaporative load, produce more than enough water to dissolve an incoming salt supply. Alternatively, the condensate can be used in other applications. The excess evaporative capacity can be used to restore the plant's water balance when NaCl is supplied as brine rather than as solid salt. Since a brine supply is usually cheaper than a solid salt supply, and since this option is not open to membrane or mercury cells without added expense, this feature is an economic advantage of diaphragm cells that helps to offset the expense of caustic evaporation.

*Example.* We consider 100 tons of cell liquor containing 11% NaOH and 15% NaCl:

	To evap.	From evap.	Vapor
NaCl	15	0.12	
NaOH	11	11.0	
$\text{H}_2\text{O}$	74	10.9	63.1



A generous allowance for the fresh salt required to produce 11 tons of NaOH would be  $1.6 \times 11 = 17.6$  tons. The water required to produce 25% brine then is  $3 \times 17.6 = 52.8$  tons. The amount of condensate recovered from the evaporator (63 tons) is about 20% more than this.

Evaporator process condensate has many potential uses:

1. utility stations in caustic area;
2. pump seals;
3. line washing;
4. evaporator wash/boilout;
5. caustic dilution;
6. soft water replacement;
7. instrument purge;
8. evaporator mesh wash;
9. centrifuge cake wash (chilled);
10. Glauber's salt crystallizer makeup (chilled).

Evaporator condensate is contaminated by entrainment of caustic. This is not a troublesome impurity in a caustic plant, and it has some positive benefits in making the water less corrosive. There is also the possibility of low-level contamination by metal ions from the processing equipment [14].

A special application of process condensate in a diaphragm-cell plant is in evaporator cleaning and boilout (Section 9.3.3.3). The salt crystallizing in the evaporators (NaCl or triple salt) continuously deposits on the surfaces of the vapor bodies and heating elements. In the latter case, it restricts circulation of liquor and can interfere with proper operation. The first symptom of a solids buildup usually is an increase in the temperature rise through the heating element. From time to time, it becomes necessary to interrupt operation in order to remove at least part of the salt deposit. The first effect usually has the heaviest deposit and requires the most frequent washing.

Depending on the extent of the buildup, there are two techniques for dissolving the deposited salt. In the less elaborate and less disruptive technique, some of the slurry is removed from one effect and replaced with water. This temporarily increases the solubility of salt in that effect. This technique, sometimes referred to as a "fly boilout," is usually the first line of attack. The more thorough complete boilout requires complete draining of an effect into a special boilout tank and replacement of the contents with water. After heating and recirculating for about an hour, the solution is dumped and replaced with slurry from the boilout tank. To conserve product and condensate, a boilout system such as that shown in Fig. 12.7 may be installed. Evaporator condensate is the normal source of water for the boilout system. For washing of small equipment or for a fly boilout of one of the evaporators, the condensate supply can be directly from its storage tank. The wash liquor then goes to the boilout water tank. This liquor can be used in either type of boilout and can be supplemented with condensate when necessary. When the boilout liquor becomes concentrated, it is transferred to the boilout collection tank, from where it is returned at a controlled rate to the evaporators.

A complete boilout is required when the simpler technique fails to restore operation for an adequate time. Maintenance shutdowns for other reasons also give opportunities



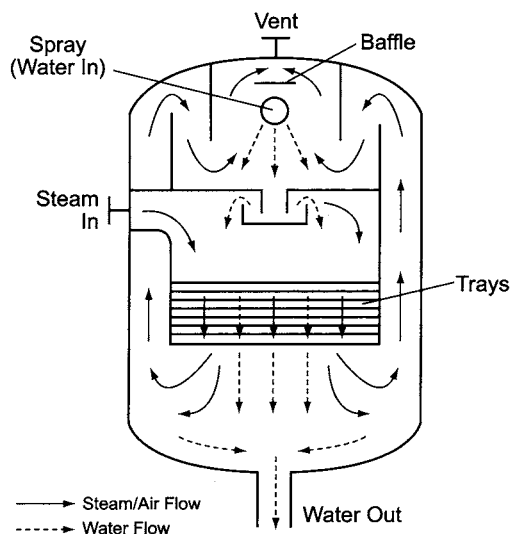


FIGURE 12.8. Condensate/feed water deaerator.

species decompose at high temperature, releasing  $\text{CO}_2$ . As steam condenses, the  $\text{CO}_2$  dissolves and forms the corrosive  $\text{H}_2\text{CO}_3$ .

Stripping the water with steam in a deaerator reduces the dissolved oxygen to very low levels. Figure 12.8 shows a typical deaerator. Spray-type units are more compact and usually cheaper than tray-type units. They are also less flexible in operation, and the example chosen here therefore is a parallel-downflow tray deaerator. Counterflow units, again, are cheaper but have narrower ranges of efficient operation. In the drawing, the water to be deaerated enters the top chamber through a sparging device or a perforated distributor. The huge increase in liquid surface area makes it possible for entrained air to escape.

The water collects in a central well and overflows a weir into the tray section. Here, it falls from tray to tray, and deaeration is completed by contact with the steam. Stripped gases and any uncondensed steam leave through a top vent. The construction of the apparatus forces the steam to flow along with the deaerated water through the tray section. At the bottom, the steam separates from the water and rises through a baffled chamber to the top section, where it meets the incoming water. The deaerated water leaves through a sealed tailpipe into a collecting drum. From here, it can be pumped to the boilers. An efficient deaerator can produce water with 7 ppb of dissolved oxygen. Achieving lower levels requires chemical treatment, discussed below.

Alkalinity is removed by the methods noted in Section 12.4.3.1 for demineralized water. It may also be useful to mitigate the effects of residual  $\text{CO}_2$  in the steam.

Strict control of purity relies on the avoidance of corrosion in the steam-distribution system and on chemical treatment of the feed water or steam condensate [15]. Treatment chemicals may include:

1. oxygen scavengers (reducing agents, including sulfites);
2.  $\text{CO}_2$  neutralizing agents (organic amines);

3. corrosion inhibitors (film-forming amines);
4. antiscalants (sequestering agents).

Oxygen scavengers such as sulfites perform best at alkaline pH. Activators can increase their rate of reaction with oxygen 10- or 30-fold [1], but the low concentration of reducing agent and even lower concentration of oxygen keep the rate low. The scavenger needs some time to react. Furthermore, other treatment chemicals can affect the scavenger or at least its activator. The order of addition of the various chemicals therefore is important, and the best practice is to add the scavenger to the bottom of the deaerating tower or into the deaerator storage tank. The other chemicals then can be added downstream.

The neutralizing amines must be deposited throughout the steam distribution piping if they are to be effective. Each plant must have a program and usually a mixture of amines selected for varying volatilities in order to achieve good distribution.

The corrosion inhibitors operate by forming a film on pipe and equipment surfaces. The amines used in this service have higher molecular weights and so are less volatile and less soluble in water. They must be injected into steam lines, and high velocity helps their distribution.

The antiscalants include chelating agents and polymers that can disperse corrosion products and other solids that may enter the system.

Excessive use of treating chemicals not only carries the obviously higher material cost but also increases the amount of condensate blowdown that must be taken from the system to control the dissolved solids concentration.

## 12.5. AIR SYSTEMS

Compressed air is supplied as a utility in several different forms that for the most part are distributed separately:

1. plant or service air
2. instrument air
3. dry air
4. breathing air

For convenience, we include nitrogen, an important utility in chlor-alkali plants, with the air systems.

### 12.5.1. Plant or Utility Air

“Plant air” is that used as a general utility. Consumers are utility stations, flushing and purging systems, power tools, certain drives, cell room cranes, cell switches, some diaphragm pumps, and various steps in filtration and ion-exchange processes. This air is not necessarily bone dry but should be free of oil and water droplets, and it should be at a pressure sufficient to operate special tools or apparatus. It is generated by compressing atmospheric air and cooling it to condense some of the water vapor. There must be precautions against the ingress of chlorine at the compressor suction. These include selecting the location for the intake and elevating it above the likely level of chlorine

accumulation. The intake should be in a cool spot away from walls and roofs and away from or on the upwind side of vents or stacks that might introduce contamination. This discussion raises the opportunity to mention the consideration of prevailing winds in plant design. While it is always useful to know the direction of the prevailing wind, designers should recognize that at most sites the wind very frequently blows in other directions. Design must cater for these cases. The placing of an air compressor intake is a good example. In most cases, the wind alone cannot be relied on to allow an air intake anywhere in the vicinity of a potential chlorine vent.

Most uses of plant air are intermittent. Design frequently provides an intake filter, a buffer tank for compressed air, and a set of pressure switches to take the compressor on and off load. The buffer tank should be large enough to prevent excessive cycling of the compressor, and the compressor should be capable of pressures high enough above the minimum header supply pressure to provide off-line periods of reasonable length.

The above describes a standard air compression package, and many commercial models are available. Reciprocating compressors are a frequent choice, and in their case, the air buffer tank also serves as the outlet dampener. The small clearances in reciprocating machinery require better filtration than is offered by a fabric strainer at the intake point. Suction strainers on these compressors, therefore, usually are rated at about 20 mesh. Each stage of the compressor has temperature measurement and alarm. Often, cylinders are jacketed for cooling, and the system may have electric heating for use at startup. Other instrumentation measures the pressure of the gas and of the lubricating oil. The oil system includes a hold tank or sump, positive-displacement pumps, circulating piping, coolers, and filters. Pressure instrumentation on the oil system includes low-pressure alarms and an emergency shutdown when the pressure is dangerously low. Low pressure also may be used to start the spare oil pump automatically, in order to forestall shutdowns. The shells of the coolers are carbon steel or the plant's standard material. To reduce the amount of corrosion products, the tube-side construction may be based on more resistant materials such as maritime alloys.

Some applications require a high volumetric flow of air for a short time. These include purging and the use of air to displace liquid from equipment before opening or performing a cyclic operation. If a system were designed to meet their needs directly from the compressor when required, it might have a large capacity that is used infrequently. Local buffer/storage tanks can smooth these demands and help to keep the size of the air compressor within reasonable bounds. It also can pay to meet high-volume, low-pressure demands with dedicated blowers. An example cited in Section 7.5.4.1 is air scouring of bed filters before backwash.

Compressed air lines are often fitted with filters, regulators, and lubricators. These are usually installed as a set. The filter may be of standard design, to remove moisture and solids, or a coalescing filter, to remove aerosols of compressor lubricating oil. The purpose of the regulator is to adjust the pressure of the air. The lubricator injects a small amount of oil, which provides downstream lubrication. The regulator is mounted between the other two appliances so that it will handle only clean air.

A system that is not leaktight will incur the expense of replacing the lost compressed air. Leaks may be due to defective hoses, worn power tools, and faulty clamps, as well as to the more classical faults in the piping itself. A single hole 1 mm in diameter will

lose about  $4 \text{ m}^3 \text{ hr}^{-1}$  of air if the line pressure is 700 kPa. The power lost is about 0.35 kW [16].

The control arrangement described above allows the pressure in the air receiver to fluctuate over a range of perhaps one bar. Because compressor drives will overheat if started and stopped too frequently, most operate in an idle mode when not compressing air. Typically, a compressor unloads when it reaches a set pressure and then continues to run unloaded for some predetermined time before shutting down. In an active system, the demand for air usually causes the compressor to cut in again before a shutdown occurs. Depending on the type of control system, an idling machine continues to consume 25–75% of full-load power. Recent developments in air compression systems use variable-speed drives on rotary screw compressors to achieve overall power savings of 20–35% [17]. By matching their output more closely to demand, these not only reduce the power consumed by off-load operation but also reduce the variation in system pressure to a small fraction of that experienced in a conventional system.

Typical distribution pressures are 550–1,000 kPa. At these levels, each kilowatt-hour used produces  $5\text{--}10 \text{ Nm}^3$  of compressed air. Each of these requires about 100 kcal of cooling. These figures obviously vary greatly with delivery pressure, inlet air temperature, etc., but they are presented to give the reader a feel for the requirements.

Many compressors require noise attenuation. The simplest type of silencer is the absorption tube. This consists of a flanged perforated tube attached to the air line and surrounded by a larger cylindrical section. The annulus is packed with steel wool, fiberglass, or felt. The size depends on the size of the piping and the degree of attenuation required. Since the energy decays exponentially as the air travels through the tube, the decibel measurement drops off linearly with distance. The efficiency of absorption depends on the nature of the packing and the frequency of the sound. It may be necessary to consider the spectrum of sound produced by the compressor and to size the attenuator on the basis of some limiting frequency.

A sound-absorbing chamber is usually more efficient than the simple tube just described. This is a pressure vessel with diameter much greater than that of the air pipe. It is divided into two or three sections, depending on the degree of attenuation needed. Perforated pipes that are not on the centerline of flow connect these sections. The changes in direction help to deaden the sound. Other devices combine the characteristics of the two types described here.

Water will condense in the lines when air is exposed to temperatures lower than that at the compressor aftercooler. This water must be drained. At subzero temperatures, the condensate can freeze in the lines, and design must address this problem. Some plants dry all their compressed air, using the techniques of the next section, in order to mitigate these problems. In this connection, refrigerated dryers that produce dew points of about  $5^\circ\text{C}$  are usually considerably cheaper than desiccant dryers.

### 12.5.2. *Purified Air*

Air used in the process or in instruments and their tubing must be quite dry. In a chlor-alkali plant, maintenance work is often necessary in areas in which chlorine vapor may be present. A secure supply of uncontaminated air is then necessary, and some plants

provide a dedicated breathing air system to meet this need. This section discusses the drying of air for the former application and the purification and distribution of air for the latter.

*12.5.2.1. Instrument Air and Dry Air.* Instrument air and “dry air” intended for use within the chlorine processing system both must have very low dew points. A common specification level is  $-40^{\circ}\text{C}$ , but the specification particularly for dry air may be lower. Modern plants meet this demand by using desiccant dryers. Drying agents include silica, alumina, and molecular sieves. The size of the desiccant beds depends on the flow rate and the inlet humidity of the air. The latter is one of the important general project criteria. The drying system sits in line after the compressor’s outlet buffer and has at least two beds of desiccant. While one operates, the other is regenerated. There are two common modes of regeneration. In one, heating the bed while sweeping it with air drives off the adsorbed water and restores the capacity of the desiccant. The regenerating air and the evaporated moisture exhaust to the atmosphere. This also can be a closed-loop regeneration, with the air or nitrogen from the bed cooled to remove water, recompressed, and reheated to provide the energy to drive off more water. Heating can be by high-pressure steam, fuel, or electricity. External heaters, on the regenerating gas line, and internal heating elements both are used. With the latter type, special care is necessary in order not to overheat some of the desiccant. The regeneration schedule includes time for heating and cooling the bed. The second mode of regeneration uses the pressure-swing technique. Some of the dry compressed air from the working bed is let down nearly to atmospheric pressure and sent to the off-line bed. The combination of low pressure and dryness gives the air a great capacity for moisture, and it is able to remove the water from the exhausted bed very efficiently. This air can be heated to supply the energy of vaporization of the adsorbed water. The supply compressor and the drying beds must be sized to handle the regenerant flow as well as the process demand. The regenerant flow depends on the outlet pressure of the working bed (pressure loss in the drying system usually is about 30 kPa). The flow can be less at higher pressure. As a first approximation, the amount of regenerant purge necessary to maintain a final dew point of  $-40^{\circ}\text{C}$  is

$$\% = \frac{12,000}{P} \quad (7)$$

where

% = required recycle, % of output

$P$  = bed outlet pressure, kPa

At a pressure of 600 kPa, for example, 20% of the air must be recycled (a 25% increase in throughput). More recycle would be necessary to maintain a lower dew point.

In any case, the operating and regeneration times are equal (a practical necessity in a two-bed system) and usually are several minutes each. Several operating systems were

found to be designed with an air space velocity in the drying columns of about  $6 \text{ min}^{-1}$ . This may vary widely. With the short running time of an individual bed, automatic switching is the normal practice.

With their similar specifications, instrument air and dry air can be generated in the same system, but they should be supplied in separate headers. There is nothing unusual about the instrument air supply in a chlor-alkali plant, and so it will not be discussed separately in this book.

Dry air is used when air is to be injected into the process anywhere on the high-pressure side or after the drying columns on the low-pressure side. When dilution of the tail gas is necessary in order to prevent accumulation of dangerous concentrations of hydrogen, the major consumer will be the liquefaction system. Other points of use include compressor seals, purging and maintenance connections, suction chiller bottoms pot connections, and anhydrous caustic processing equipment.

The immediately obvious hazard in a dry air distribution system is the entry of chlorine into the air lines during pressure reversals. Some plants use non-return valves to protect against this. The reliability of these valves is questionable, and the authors recommend the use of automatic valves that close when the differential pressure across them reverses. Figure 11.51 illustrates this technique in a different application. These valves can be used in conjunction with non-return valves when some redundancy is desired. Section 12.7.2 reviews some of the arrangements used to connect air and other utilities to process systems.

The dry air supply can be backed up by nitrogen or instrument air when the available supply of those utilities is large enough. They can also be used as backup or replacement at individual locations, subject to the caveat of Section 12.5.3.

**12.5.2.2. Breathing Air.** Breathing air systems should be dedicated and not integrated (except possibly at the atmospheric side) with other air systems. Oil-free compressors are necessary, with intake and outlet filters and frequently a carbon adsorber to purify the air. The air must not be bone dry. It should have enough humidity to keep a worker comfortable. The delivered air should meet the Compressed Gas Association's specification G-7.1. Electric motor drives are preferred, as they are least likely to contaminate the air intake. The compressor should have a high-temperature alarm, and the quality of the air should at least be checked frequently.

In the air distribution system, all takeoffs should be from the top of the pipe or header. Headers should slope towards their ends and should include terminal drain/blowdown valves. Connection points for hoses should be standardized throughout each plant and should carry prominent reminders to blow out the line before use.

There are two types of mask in general use—constant-flow and demand-supply. Tight-fitting constant-flow masks require about  $7 \text{ Nm}^3 \text{ hr}^{-1}$  of air. The loose-fitting type requires about 50% more. Demand-type masks require up to  $3 \text{ Nm}^3 \text{ hr}^{-1}$ . Ventilated suits will consume  $25\text{--}50 \text{ Nm}^3 \text{ hr}^{-1}$ .

Breathing air is not supplied as a pipeline utility in all plants. There are many approaches to the problem of supplying emergency breathing air, each with its own set of advantages and disadvantages, as summarized in Table 16.1.

There should be no connections of breathing air to process systems. Connections to other air systems should be made only after thorough review (Section 12.7.2).



### 12.5.3. Nitrogen

Nitrogen is valuable for its dryness and its inertness. Both are useful in the chlorine process, and inertness is desirable in the hydrogen process. Most plants purchase nitrogen as the liquid and supply it to the processing units through a packaged vaporizer, which often remains the property of the gas supplier.

Nitrogen is much more expensive than air, and the possibility of its entering an air distribution system must be rigorously excluded because of its asphyxiant properties. It offers some advantages in compensation. Its dew point usually is lower than that of dry air, and its dryness is more reliable and not subject to desiccant bed breakthroughs. In tail gas processing, while this may not be recognized in the specifications set for hydrogen content, nitrogen is also a more effective diluent than air (Section 9.1.11.1).

### 12.5.4. Backup Systems

Backup supplies are always useful when a utility is lost. Spare equipment or multiple-train equipment may be used in order to keep the utility on line even if one part of the system shuts down. An alternative or supplement is to provide backup from a different utility system. The number of different air systems found in a plant provides an opportunity to do this. Moreover, nitrogen can be used to back up some of the air systems. All these tie-ins require careful review during hazard analyses. Usually, the backup supply is activated when the primary supply loses a certain amount of line pressure. If this is done by means of a single pressure regulator and the pressure is also low on the backup system, the flow may be opposite to that intended. It is essential to keep nitrogen out of an air supply to a confined, inhabited space (e.g., the instrument air supply to a control room), and it is essential to keep air out of nitrogen when it is used as an inert gas.

## 12.6. VACUUM SYSTEMS

For convenience, we include vacuum services among the utilities. While true utilities are supplied plantwide from a central location, vacuum producers in a chlor-alkali plant tend to be more dedicated to a single duty and installed near the point of use. Major applications in the process, keyed to the sections in which they are discussed, include:

1. brine sludge filtration (16.5.1.3)
2. brine dechlorination (7.5.9.2A)
3. chlorine system evacuation and purging (9.1.12)
4. caustic evaporation (9.3.3)
5. brine evaporation (7.1.5.2)
6. deaeration of brine (7.3.2.3)

The discussion of vapor-recompression evaporation in Section 7.1.5.2B distinguished between mechanical and thermal recompression. Vacuum systems (Section 12.6.1) can be divided in the same way between those relying on compressors and those using ejectors. Hybrid systems using both types are also quite common. Since the amount of vapor that it handles fixes the size of a vacuum producer, removal of evaporated water between

the process and the source of vacuum is a nearly universal technique in chlor-alkali plants. Removal of the condensate, which is under vacuum, requires special attention. Vapor condenser selection, arrangement, and piping, therefore, are important aspects of vacuum system design (Section 12.6.2). Methods of process control, principally a matter of maintaining the desired pressure at the process unit, depend on the type of vacuum producer being used (Section 12.6.3).

### *12.6.1. Sources of Vacuum*

The first step in choosing a vacuum source is the definition of its duty. The process itself dictates operating conditions, but the designer must consider both startup and steady-state operation and also take into account the leakage of air into the evacuated system. An important example of the difference between startup and steady duty is the caustic evaporator. Startup requires a much greater rate but for only a short time. Common practice therefore is to supply two sources. A large source, for example a “hogging” jet, takes care of startups. A smaller parallel unit avoids the consumption of large quantities of steam or power during regular operation.

The steady-state duty includes vapors generated in the process and air that infiltrates the equipment. Estimation of the latter quantity depends on the size and arrangement of the relevant equipment and piping. Engineers will be familiar with the curves published by the Heat Exchange Institute for what are defined as “commercially tight” systems. Here, the rate of infiltration is assumed proportional to the two-thirds power of system volume. More elaborate, and one presumes more accurate, methods take account of the number, sizes, and types of fittings, valves, welds, etc. These methods and the standard factors for estimating leakage are in the publications of vacuum system vendors [18] and in process engineering textbooks [19].

The choice of apparatus normally comes down to a selection of steam jets or mechanical equipment. Important design factors include:

1. gas(es) to be handled;
2. process load (minimum and maximum);
3. air leakage;
4. allowable pump-down time;
5. range of pressures required;
6. presence of entrained solids or liquids;
7. noise.

The nature of the gases being evacuated determines the materials of construction and their molecular weight influences the duty of the vacuum producer. Items 2–4 fix the capacity. In addition to the usual overdesign factors one finds in process work, the allowance for air inleakage is often quite generous. Vacuum systems, as a rule, are well oversized for their actual duty. When the system remains tight, this has implications in process control (Section 12.6.3). Item 5 is an important differentiator among vacuum systems, and it usually determines the number of stages required. In normal chlor-alkali vacuum applications, which exhaust at essentially atmospheric pressure, the suction pressure is the determining variable. In vapor-recompression operations, the discharge pressure is equally important. Solids entrainment can affect the equipment by erosion and can

seriously reduce the capacity of a steam jet. Solids also can damage sliding-contact vacuum pumps. While the more elaborate mechanical pumps offer high efficiency and minimum pollution, they are limited to service with clean, dry gases and also suffer from the need to displace large volumes of gas at low pressure. Liquid-ring pumps are more common in chlor-alkali plants. They offer higher thermal efficiencies than steam jets and can handle higher concentrations of entrained solids or liquids. In closed-circuit systems, they also produce less pollution. Steam jets are very simple, with no moving parts, and are the cheapest systems to install. Here, we consider only liquid-ring pumps and steam jets. The Heat Exchange Institute publishes "Performance Standards for Liquid Ring Vacuum Pumps" and "Standards for Steam Jet Vacuum Systems." Members of the relevant committees [20,21] have published summaries of the major points of the then-current standards.

*12.6.1.1. Liquid-Ring Pumps.* Many smaller plants, in particular, compress chlorine with liquid-ring pumps. Section 9.1.6.2C discusses the mechanism of their operation, and Fig. 9.23 is a typical flowsheet. Here, we consider them as sources of vacuum.

Liquid-ring systems differ in their handling of the pumped seal liquid. Once-through systems discharge all the liquid from the gas-liquid separator into a collection system or send it to waste. This has the advantage of simplicity and is the basis for many systems that do not handle chlorine. Brine filtration is an example. It is unacceptable when discharge of the liquid presents a pollution problem. The opposite approach, full recycle of the liquid as in Fig. 9.23, minimizes discharge but involves the expense of a recycle cooler and, in many systems, a recycle pump. An intermediate approach is to provide enough fresh liquid to remove the heat of compression and maintain the process temperature, and to recycle enough to satisfy the liquid-handling capacity of the pump. This technique saves much of the liquid supply without the expense of a return pump or cooler.

There always is a net change in the quantity of water in a "closed" system. When there is a net evaporation into the compressed gas, one needs simply to arrange for makeup of fresh water. If some component of the gas being compressed is absorbed into the water, there may also be a need for blowdown to control its concentration. When there is net condensation of water, as in most applications in this volume, there is a need for a controlled purge of water into an appropriate recovery system.

Discharge piping between the vacuum pump and the separator should be as simple and as low as possible. Frequently, the two are close-coupled. If necessary, some increase in elevation above the pump discharge flange is acceptable, but this puts a backpressure on the pump and increases its power demand or reduces its capacity. With the live mechanical load and the desire to keep piping compact and even close-coupled, piping stress can be an important consideration. Careful design or the use of flexible connections is necessary.

Liquid-ring pumps require shaft seals. A simple lantern-ring arrangement appears on some models and requires a flow of cooling liquid. Recycled liquid is acceptable in this duty. However, mechanical seals are preferred in most chlorine-handling applications. Double seals with separate supplies of clean fluid are the standard.

Recycle of the sealing liquid from the receiver to the pump presents no unusual or especially difficult problems. The proper materials of construction are necessary, but

design of the recycle cooler is straightforward. The liquid may be saturated with a gas such as chlorine at separator pressure. This means that the return system, especially one without a pump, must be able to handle a certain amount of evolved gas.

The basic materials of construction of a liquid-ring pump depend on the gas being removed. In non-chlorine applications, for example brine filtration, pump bodies can be of carbon steel and water can serve as the sealing fluid. There may be some upgrading of materials, particularly in small parts and seals, because of the possibility of entrainment of process liquids. When chlorine vapor is expected to be present, as in brine dechlorination or purging of certain equipment, the combination of carbon steel and a water ring is not acceptable. We have already noted the use of sulfuric acid as the liquid ring in chlorine compression. In brine dechlorination, the amount of water vapor in the gas would consume excessive amounts of acid. Since vacuum levels are modest, a water ring is operable. The material of construction problem is solved by the use of titanium or lined materials. The combination of a titanium impeller with a ceramic-lined body has found use in brine dechlorinators.

*12.6.1.2. Steam Jets and Hybrid Systems.* Steam jets have the important advantage of availability in a variety of higher materials of construction. This may be a decisive factor in, for example, brine or condensate dechlorination. Their design is simple, with no moving parts, and they can be mounted in any position and in any orientation [22]. Their operation is simple, and startup and shutdown are particularly straightforward. They can handle a gas that contains condensable components. When used in chlorine service, on the other hand, they produce vapor and condensate that are contaminated with chlorine. Backflow of steam into the process system is an inherent possibility, and process design must guard against this where it is objectionable. Steam jets also are noisy and may require housing or special insulation to meet environmental standards.

The maximum compression ratio achievable by a jet usually is about 6 or 10 : 1. Practically, ratios are limited to lower values, and multistage jets are necessary in evaporation systems. While process and equipment design have much to do with the selection of the number of stages, the tabulation below is a rough guide to the absolute pressures that can be produced by two to four vacuum stages:

No. of stages	Pressure (torr)
2	5–20
3	0.5–5
4	<0.5

Figure 12.9 is a flowsheet for a system with two stages. Mechanical pumps can achieve the ratios required in chlor-alkali plants in a single stage.

Ejectors must transfer work to the low-pressure fluid, and so there is always a loss of enthalpy from the system. Expansion of the motive steam and compression of the mixed fluid are more nearly isentropic [23]. An isentropic expansion can cross the saturation curve and enter the two-phase region. This fact is an important consideration

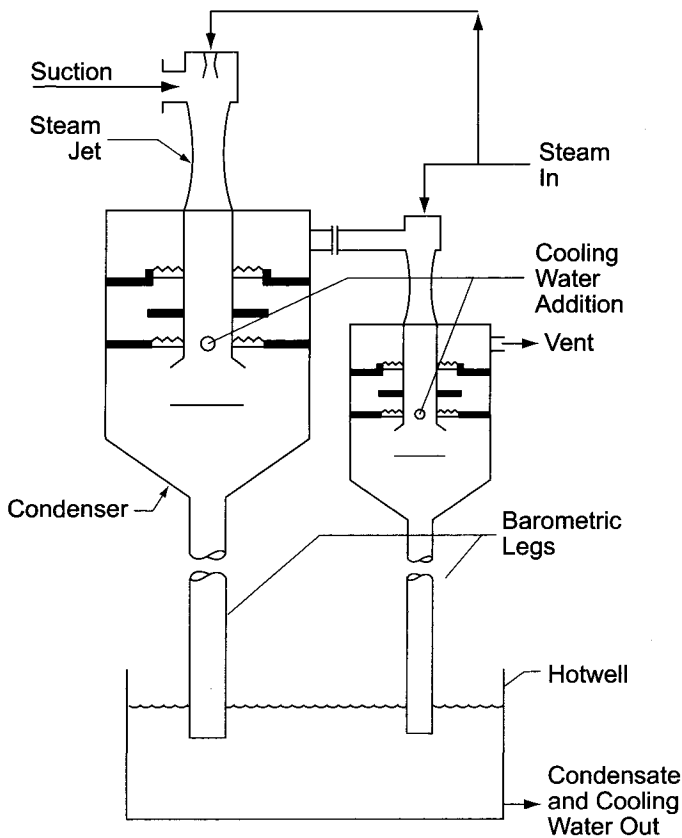


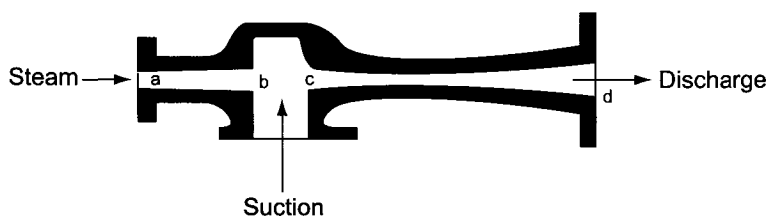
FIGURE 12.9. Two-stage steam-jet vacuum system with barometric condensers.

in the design of ejectors. The loss of enthalpy and the entrainment ratio produced, both functions of the efficiency of the jet, are important to the design of the evaporation plant.

To analyze the behavior of an ejector, we recognize three distinct stages of operation, as shown in Fig. 12.10:

1. the motive steam expands and produces work (a–b);
2. the expanded steam transfers some of its momentum to the fluid which is to be entrained (b–c);
3. deceleration of the mixed fluid in the expansion zone (the diffuser) abstracts work from the fluid and produces higher pressure (c–d).

We assign the efficiencies  $\eta_1$ ,  $\eta_2$ , and  $\eta_3$  to these regimes. The unit enthalpy of the mass  $M_1$  of motive steam at supply conditions is  $H_1$ . After isentropic expansion to the pressure in the nozzle, this enthalpy becomes  $H_2$ . The steam entrains the mass  $M_2$  of low-pressure vapor, and the unit enthalpy of the mixture at low pressure is  $H_3$ . The mixture, of mass  $M_1 + M_2$ , is compressed in the diffuser and acquires the unit enthalpy  $H_4$  at the outlet of the ejector.



Gas	Point	Flow	Pressure	Enthalpy
Motive Steam	a	$M_1$	$P_1$	$H_1$
Expanded Steam	b	$M_1$	$P_2$	$H_2$
Mixed Gas Diffuser	c	$M_1 + M_2$	$P_2$	$H_3$
Discharge	d	$M_1 + M_2$	$P_3$	$H_4$

FIGURE 12.10. Analysis of steam-jet operation.

The work produced by isentropic expansion of the motive steam would be  $M_1(H_1 - H_2)$ . Applying the efficiency of this step,  $\eta_1$ , we have

$$W_E = \eta_1 M_1 (H_1 - H_2) \quad (8)$$

The total amount of work produced in the process also depends on the efficiency of momentum transfer,  $\eta_2$ :

$$W_P = \eta_1 \eta_2 M_1 (H_1 - H_2) \quad (9)$$

The work required for isentropic compression in the diffuser would be  $(M_1 + M_2)(H_4 - H_3)$ . Since work is supplied at the efficiency  $\eta_3$ , we have for the actual work of compression

$$W_C = \frac{(M_1 + M_2)(H_4 - H_3)}{\eta_3} \quad (10)$$

The work produced ( $W_P$ ) must equal the work consumed ( $W_C$ ), and so we have

$$E(H_1 - H_2) = \frac{(H_4 - H_3)(M_1 + M_2)}{M_1} \quad (11)$$

where  $E$  = combined efficiency  $\eta_1 \eta_2 \eta_3$

Solving for the entrainment ratio  $R_e = M_2/M_1$ :

$$R_e = \frac{E(H_1 - H_2)}{(H_4 - H_3)} - 1 \quad (12)$$

Typical values of  $E$  are 0.75–0.80. Note that this is a mechanical efficiency calculated from the effectiveness of transfer of kinetic and compression energy, with the steam

discharged along with the process load as a gas. In the typical evacuation process, the steam is condensed and its latent heat wasted. The thermal efficiency of a steam-jet installation, therefore, is usually quite low.

*Example.* We wish to operate an evaporator at 165 kPa with condensing steam at 205 kPa. Saturated steam is available at 1,135 kPa for thermal recompression of the vapor. From the steam tables, the enthalpies in  $\text{kJ kg}^{-1}$  at the connection points are:  $H_1 = 2,782$ ,  $H_2 = 2,442$ ,  $H_4 = 2,707$ . Equation (12) also requires  $H_3$ , which is the enthalpy at an internal point. Its estimation requires the use of the individual efficiencies described in the text. We assume  $\eta_1 = 0.98$ ,  $\eta_2 = 0.85$ , and  $\eta_3 = 0.95$ .

$H_2$  is below the saturation enthalpy, and so there will be some condensation of the motive steam. First, we calculate  $H_{2'}$ :

$$H_1 - H_{2'} = \eta_1(H_1 - H_2) = 0.98(340) = 333.2$$

$$H_{2'} = 2,449$$

This corresponds to a steam quality of about 89%. This is the result of just the expansion of the motive steam. After it transfers momentum to the evaporator vapor, the enthalpy is lower and the quality correspondingly higher:

$$(1 - \eta_2)(H_1 - H_2) = (x_{2''} - x_{2'})\lambda = 51$$

where  $\lambda$  is the latent heat of vaporization ( $2,220 \text{ kJ kg}^{-1}$ ) and  $x_{2'}$  and  $x_{2''}$  are the steam qualities before and after transfer of momentum. This process, therefore, raises the quality to about 91%. Isenthalpic mixing of the expanded steam with the process vapor once again increases the quality (barring entrainment of liquor from the evaporator). Since we do not yet know how much vapor is entrained by the steam, this new quantity,  $x_3$ , requires trial-and-error calculation. Since our interest is in the method, we anticipate the result and write  $x_3 = 0.95$ . Applying this at the conditions of the nozzle, we have  $H_3 = 2,588$ . The mixture leaving the ejector has the enthalpy  $H_4 = 2,707$ . Now we can write

$$\begin{aligned} R_e &= E(H_1 - H_2)/(H_4 - H_3) - 1 \\ &= (0.98)(0.85)(0.95) \frac{(2,782 - 2,442)}{(2,707 - 2,588)} - 1 \\ &= 0.7913(340)/(119) - 1 = 1.26 \end{aligned}$$

Each weight of motive steam therefore entrains 1.26 weights of vapor. About 45% of the flow from the ejector nozzle is newly added steam. This number varies inversely with the enthalpy of the motive steam and directly with the compression ratio of the process vapor. The consumption of fresh steam is a fundamental limitation on the steam economy that can be achieved in thermal recompression.

The motive steam to a jet should be dry, with some superheat, and at a pressure suited to the rating of the jet. A pressure regulator in the steam line can produce some

superheat if any liquid droplets in the supply first are removed. Most jets operate in the range of 5–15 bars, but some are designed for high-pressure steam. It is most important to keep the steam dry, and designers should ensure that the lines approaching a jet are well insulated, always remembering that instrument connections can be small condensers.

When the process requires a high compression ratio, ejectors can be installed in series. The simplest arrangement for a multistage ejector system would simply feed the output of one stage to the next. The later stage therefore would have to educt the steam from the earlier stage along with the process load. In a multistage system, this can lead to large multiplication of steam flows. Once the absolute pressure is high enough to produce a dew point well above the cooling water temperature, it becomes economical to install interstage condensers. These remove condensable vapor and so reduce the load on subsequent stages. They also limit the carryover of solids and process liquids and can reduce the concentrations of corrosive substances in the vapor. An aftercondenser will have the same effects and will reduce the amount of steam exhausted to the atmosphere. We discuss types of condensers in the next section.

Steam jets operate off the kinetic energy of the motive steam and make little use of its heat content. Their thermal efficiency as a consequence is very low. As kinetic energy machines, however, their efficiency does not suffer from the large volumes of gas that must be moved when the pressure is low. At 50 torr, for example, the specific volume of saturated water vapor is about  $25 \text{ m}^3 \text{ kg}^{-1}$ . Displacement-type machines increase rapidly in size and begin to work very hard as suction pressure declines. Below about 10 torr, their thermal efficiencies begin to fall into the same region as those of steam jets [24]. Water-ring pumps in particular lose efficiency at deep vacuum, where the vapor pressure of the water becomes a significant fraction of the suction pressure. The comparative advantages of vacuum producers, therefore, shift with the design suction pressure. In a multistage system, this creates the opportunity to assemble a system more cost-effective than one based entirely on either pumps or jets.

Hybrid systems can combine the relatively high efficiency of steam jets at low pressure with the better performance of liquid-ring pumps at higher pressures. The steam jet(s) will be the first stage(s) in the system. After the vapor that is being exhausted has reached a sufficiently high pressure, a liquid-ring pump raises it to atmospheric pressure. Figure 12.11 shows the thermal efficiency of a hybrid system compared to those of steam jets on the one hand and a two-stage liquid-ring pump on the other. At high suction pressures, the hybrid arrangement is no more efficient than the liquid-ring system. At lower suction pressures, where the efficiency of the pump begins to fall off rapidly, the efficiency of the hybrid system declines much more slowly. In the example shown, at those suction pressures where liquid-ring pumps are not functional, the use of a pump as the final element gives a system more than three times as efficient as one based on steam-jet ejectors alone.

### 12.6.2. Vapor Condensers

Condensers may be indirect surface units or direct-contact barometric condensers. Surface units prevent contamination of the water used for cooling. This may be a decisive advantage when waste treatment of the cooling water is necessary. Barometric condensers usually are cheaper and are widely used in chlor-alkali applications. In a caustic



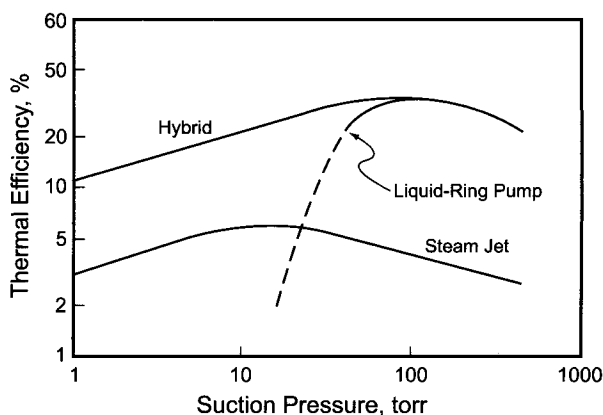


FIGURE 12.11. Relative efficiency of combination of jet and vacuum pump.

evaporator, for example, plant cooling water often is used as the cooling medium and then returned, along with water condensed in the process, to the sump of the cooling tower. With properly selected locations, this return can be by gravity. The condensed vapor becomes high-grade makeup water to the cooling tower.

An essential feature of a barometric condenser is its elevation. As Fig. 12.9 shows, the discharging water must be at atmospheric pressure at the point of overflow from the collecting vessel, or hot well. The tail pipe (or “barometric leg”) connecting the condenser and the hot well must provide enough static pressure to overcome the difference between the system pressure and the atmosphere.

The barometric condenser depicted in Fig. 12.9 is a countercurrent-flow unit. Some units operate in cocurrent flow. One of the advantages of the countercurrent arrangement is the closer approach that is possible between the temperature of the discharged water and its saturation temperature. In a well-designed unit, this can be as little as 2.5–3°C. The cooling water flow required is

$$W = \frac{Q}{t_s - t_w - t_a} \quad (13)$$

where

$W$  = water flow,  $\text{kg hr}^{-1}$

$Q$  = heat duty,  $\text{kcal hr}^{-1}$

$t_s$  = saturation temperature of vapor, °C

$t_w$  = inlet temperature of cooling water, °C

$t_a$  = temperature approach, °C

Any of the common heat/mass-transfer devices can, in principle, be used to subdivide the water flow. Spray systems and baffle plates are most common.

Piping arrangements are very important [25]. Pressure drops must be very low because of the low absolute pressure on the gas side and the use of flashing gravity flow on the liquid side. Condensate piping between condensers and hotwells should have a

continuous slope of at least  $45^\circ$  and as few changes in direction as practicable. The tail pipe should be submerged at least 30 cm in the hotwell and should end at least 30 cm above the floor. In a very large system, the distance of the end of the tail pipe from the floor of the hotwell should also be more than half the diameter of the pipe. Vapor lines should be arranged to prevent accumulation of liquid. Because of the possible condensation of vapor, they should have no pockets, and their connections to condensers should prevent any backup of condensate or, in a direct-contact condenser, cooling water.

The height of the tail pipe should be comfortably above the equivalent height of a column of water at the highest atmospheric pressure that may be encountered. The recommendation of the Heat Exchange Institute is equivalent to about  $102 \text{ mm kPa}^{-1}$ . Finally, the size of the hotwell should conform to the length and diameter of the tail pipe, with a 50% margin in its volume. When condensate is removed by pumping from the hotwell, it should also meet the usual holdup requirements of a pump tank.

All references to water and condensate so far have assumed that they are removed at atmospheric pressure. It is also possible when desirable to remove them while still under some vacuum. This permits the use of a lower-level condenser but requires a pump of proper design for the service.

The pressure drop in vapor piping should be very low. What is considered a reasonable line loss in a pressurized system can be a substantial fraction of the absolute pressure needed at the source. Line velocities also should be limited. At typical dechlorination system pressures, a maximum of  $45 \text{ m s}^{-1}$  is desirable. With evaporators operating below 10 kPa,  $55 \text{ m s}^{-1}$  is more typical.

### 12.6.3. Process Control

The discussion of vacuum sources pointed out that most are well oversized for their duty. Most systems, therefore, have some form of pressure control. Control can be by throttling or, more often, by addition of a false load. Pressure control by suction throttling does not reduce the energy consumed by a jet or a liquid-ring pump with a given duty. Rather, by increasing the vacuum at the source it can increase the duty by allowing more air inleakage.

The false load added to provide control will be steam or air. The best choice for a steam-jet system is steam, which condenses in the interstage exchangers and adds very little to the loading on following stages. Air, on the other hand, passes through the system and carries uncondensed water with it. All this vapor becomes part of the load on the ejectors. The control steam can be supplied from the plant mains or, with less cost and somewhat lower effectiveness, it can recycle from the outlet of one of the jets. Air is a better choice for the false load on mechanical pumps, as it avoids any problem with condensation of water in the machinery. Liquid-ring pumps can accept either air or steam. The use of air adds less to the cooling load. In the case of brine dechlorination, however, added air accompanies the regenerated chlorine into its recovery process. When this process is liquefaction, the air reduces the efficiency of recovery, and so the use of steam is preferred.

With a liquid-ring pump, as with most mechanical systems, the most energy-efficient means of pressure control is a variable-speed drive on the pump. There is a

particular limitation in this case, however, because a certain minimum speed is necessary to keep the rotating ring of liquid intact. Another characteristic of the liquid-ring pump is that it requires a certain minimum load in order to avoid cavitation. It is not possible to run such a pump under shutoff conditions without a bleed line from the receiving vessel back to the pump casing.

An alternative already discussed for the dechlorination process is operation without pressure control (Section 7.5.9.2A). In situations where there is no harm in allowing the vacuum to go beyond that strictly required by the process, the excess capacity inherent in a vacuum producer may help a process by producing results better than design.

## 12.7. UTILITY PIPING AND CONNECTIONS

### 12.7.1. Utility Piping and Headers

Utility headers for the most part are carbon steel. Construction is conventional, and steam piping is probably the most specialized, its wall thickness and construction being functions of the pressure level. The sizes of the major headers give them great influence on the layout of pipe racks and equipment location. Sizing of utility headers differs from sizing of process lines in several ways:

1. Utility headers are more likely to be designed for later expansion, because
  - (a) increased demand may be caused by addition of new operations as well as by expansion of capacity
  - (b) modular expansions of production capacity usually are not accompanied by expansions of utility capacity in the vicinity of the process. Rather, the utility capacity is increased in the “utility area,” and the traffic in the main headers increases
  - (c) later duplication or replacement of utility headers is extremely disruptive as well as expensive. Pipe racks, unless designed for expansion, may lack both space and structural strength
2. The pressure drop per unit length of pipe is lower in utility headers, in order to keep the total system pressure drop low, because
  - (a) the value of the utility may decline along with its pressure (steam, e.g., loses some of its thermal potential when its pressure drops)
  - (b) available pressure drop through users should be reasonably constant throughout the plant
3. Utilities are more subject to variations in flow, and the maximum may be much greater than the average.
4. Certain utility water lines are subject to fouling.

Design of utility piping should consider pressure drop per unit length, total system pressure drop, and line velocity. Limiting the velocity reduces erosion and noise level. Because of item 2 above, design pressure losses tend to be quite low. Also, velocity is more likely to be the size-determining criterion in utility headers than it is in process lines. Steam velocities depend on quality and supply pressure. Typical design rates for superheated steam are from 35 up to 100 m s<sup>-1</sup>. Saturated steam moves at 30–50 m s<sup>-1</sup>.

Sonic velocity also is a consideration when steam is handled under vacuum, as in an evaporator. It depends on the specific heat ratio and the temperature. Using a typical value of the former, we have approximately

$$u_s = 24.4 T^{0.5} \quad (14)$$

where

$u_s$  = sonic velocity in steam,  $\text{m s}^{-1}$

$T$  = temperature,  $K$

Maximum superficial condensate velocities are about  $25 \text{ m s}^{-1}$ . In a given line, the velocity increases as the pressure drops and more liquid vaporizes. Vendors of steam traps and condensate systems can provide guidance and line-sizing charts. Water lines usually have velocities up to  $3 \text{ m s}^{-1}$ . The designer must consider water hammer as well as velocity and pressure drop. Selection of valves and their closure time becomes important. Compressed air usually is transported at  $5\text{--}8 \text{ m s}^{-1}$ .

### 12.7.2. Utility-Process Connections

When utility lines are connected to process lines or equipment, there is a danger of backflow of process material into the utility system and a danger of overpressurization of one system by the other. All connections of this kind require careful study during design and hazard analysis. Many plants review similar connections as a group and develop standard details. This standardization can include formal requirements for the number of layers of protection for each group.

The hazard to be avoided may be:

1. the process material itself (e.g., chlorine)
2. the immediate physical or chemical effects of mixing the two materials (sulfuric acid and water)
3. the especially severe consequences of contaminating the utility (potable water, breathing air, inert gas) or
4. the unsuspected presence of a utility in the wrong place (intermixing of nitrogen and certain air systems)

One way to promote reliability in the separation of two fluids is redundancy, and many of the arrangements used as utility-process connections include multiple devices. Reliability also increases with quality and with features designed to enhance the action of safety devices. An example of the latter is the use of internally force-loaded check valves (FLCVs) rather than the more conventional design.

The paragraphs that follow give some idea of the considerations that apply to certain utilities. A connection to a cell-room header may also require a length of nonconductive pipe to prevent stray voltages and currents in the utility system (Section 8.4.1).

*12.7.2.1. Potable Water.* Every plant must have a potable water supply, and many use some of that water in other applications. Small plants in particular may receive all their water from local municipal (potable) systems. It then becomes necessary to prevent the backup of water connected to process systems into the drinking water system.

There are many ways to accomplish this isolation. Combinations of check valves (FLCVs preferred) with regulators sometimes are used. These combinations must have sufficient redundancy and are better suited when the potential contaminant is not highly hazardous.

Another common isolating device is the conventional backflow preventer. Figure 12.12 shows one type. Two FLCVs provide the first level of protection, along the top of the diagram. In many water applications, this may be sufficient. As an example, consider the connection of a source of minimally treated water to a neutral brine system. While backflow is undesirable, it does not create a great hazard. In more exacting applications, as in any using potable water, the automatic dumping feature of Fig. 12.12 is added. With the normal pressure gradient from left to right, the force on both diaphragms pushes the slide to the left. This is the normal (closed) position of the valve. If the direction of the pressure gradient shifts, the force on the diaphragms now pushes to the right, and the dump valve opens.

A preferred system, which the process industries increasingly tend to use, provides a free fall or an air gap to achieve isolation. Figure 12.13 is the familiar break tank. As drawn, the water supply line does not enter the break tank. It should end at least two line diameters above the flood level of the receiver. The supply line can extend into the tank if a positive overflow is provided and the proper gap is maintained between supply and overflow. Good practice then also includes a break in the overflow pipe. The disadvantage of a break tank, especially the open type, is the loss of line head when the water is held under atmospheric pressure. This can be restored by elevating the break tank or by pumping the water from the break tank for distribution.

Some systems introduce the supply below the flood level of water in the receiver. Such a system should include a vacuum breaker mounted above the receiver to prevent siphoning back into the potable water supply.

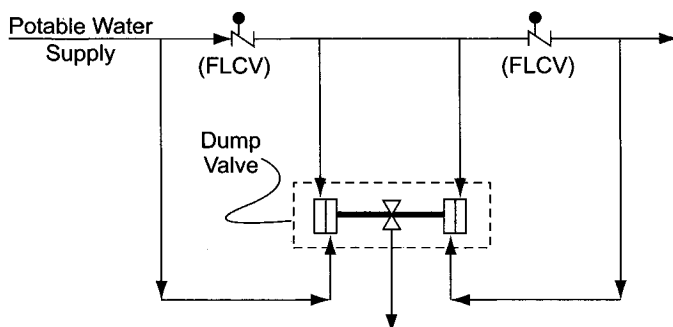


FIGURE 12.12. Typical backflow preventer.

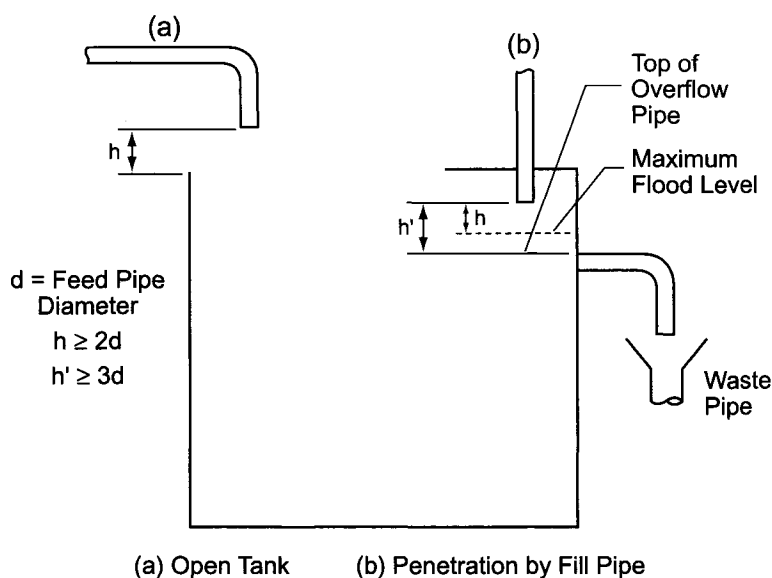


FIGURE 12.13. Potable water break tank.

**12.7.2.2. Other Water.** Lower grades of water require less stringent precautions. While any arrangement suitable for potable water can be used for other grades as well, simpler arrangements often are satisfactory. Multiple check valves without the automatic dumping feature of the backflow preventer were mentioned above. Manual disconnects (by way of flexible hose or pipe sleeve) are often used. They are most reliable when combined with a second level of protection, such as an FLCV on the process side of the break. Double-block-and-bleed systems are an alternative. Again, an FLCV (upstream of the bleed valve) improves the reliability.

**12.7.2.3. Steam.** Steam connections to process resemble ordinary water connections. Pressure usually is of more concern than contamination, and connections to process systems without adequate design pressures must include some form of pressure relief. When steam is used to purge or humidify a process system, cooling after shutdown also can produce a vacuum. Protection is then required directly on the process system.

**12.7.2.4. Breathing Air.** Breathing air is best not connected to the process or to a non-air utility system. It sometimes shares a compression system with another air system (e.g., instrument air). The separation between the two air systems then should be close to the source, for example, immediately after the receiving tank. Any connected lines should be fitted with check valves to prevent backflow into the common system. Design of an integrated system should include consideration of the possibility and effects of any other stream entering the breathing air system.

Pressure regulators should never be relied on as isolating devices. First, they do not always provide perfect shut-off. Second, if the pressure of the source falls below an already low downstream pressure, the regulator will remain open and allow massive backflow. A pressure regulator followed by a backpressure regulator will be more reliable.

**12.7.2.5. Dry Air and Nitrogen.** Dry air connections also require special attention. The dry air system exists to serve the dry chlorine end of the process, and so the problem of backflow of process material is always an important one. The connections should be chosen accordingly. In many locations, the design intent will be to have dry air enter part of the chlorine system whenever the pressure falls below a certain level. The natural approach then is to supply pressure regulators. These have the disadvantages already listed. A more secure approach is to use on-off control valves that close whenever the differential pressure across them reverses its direction.

Nitrogen may be used for the same purposes and with similar precautions. Whenever nitrogen is connected to an air system, its asphyxiation hazard requires review. If there is a possibility of infiltration into a breathing air system or release into a confined space, there must be adequate protection or abandonment of the plan to use nitrogen. An example sometimes overlooked is the use of nitrogen to back up an instrument air supply, with the possibility of use of nitrogen in a confined space behind a panel board, where there is always some amount of venting and leakage.

A similar technique, more common with air systems, is to automate the familiar double-block-and-bleed arrangement. The first step in this design might be to replace a simple check valve with a differential-pressure control valve that shuts when the pressure differential reverses. This affords two levels of protection, unless one assumes that the check valve is fundamentally untrustworthy and always allows some backleakage. Check valves can, of course, be made more reliable by proper installation and by extra measures such as force loading. An elaboration on the diagram above is to add a second valve in the line that closes when the differential pressure is too low or even negative. Finally, the space between the two in-line check valves can be vented for more positive protection.

Other elaborations might include the use of independent pressure switches rather than taking all control signals from a single transmitter. Figure 12.14 shows a typical automatic system. It also uses two block valves. The more secure arrangement has differential pressure measurement across each valve. When the pressure differential

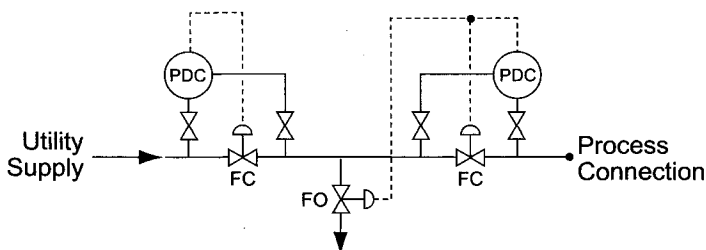


FIGURE 12.14. Automatic double-block-and-bleed system.

reverses or drops below a preset value, the valve closes and prevents flow of the utility. The downstream pressure controller also activates the bleed valve. Air failure closes the block valves and opens the bleed valve. A simpler arrangement, when the consequences of backflow are less severe, depends on a single differential pressure measurement across the assembly.

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